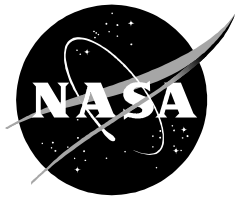


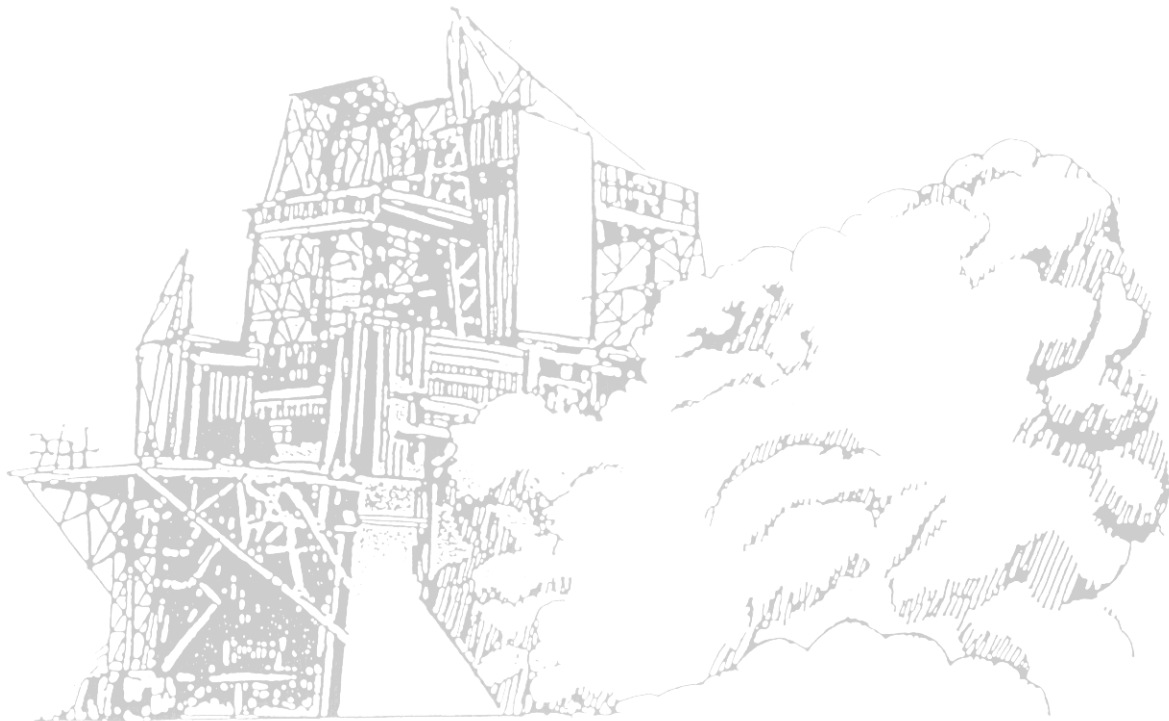
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TEST FACILITIES CAPABILITY HANDBOOK

STENNIS SPACE CENTER and MARSHALL SPACE FLIGHT CENTER

*Rocket Propulsion Test Program Office
Building 1100
Stennis Space Center, MS*



January 2007

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PREFACE

Stennis Space Center's (SSC's) and Marshall Space Flight Center's (MSFC's) test facilities, supporting infrastructure, and technical capabilities are described in this handbook, which should be considered a living and evolving document. It is organized into two volumes, Volume I containing SSC capabilities and Volume II containing MSFC capabilities. Questions related to test capabilities identified in this document and additional assistance in accessibility to the information in this document should be directed to the Rocket Propulsion Test Program Office as follows:

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TEST FACILITIES CAPABILITY HANDBOOK

Volume I

STENNIS SPACE CENTER

*Rocket Propulsion Test Program Office
Building 1100
Stennis Space Center, MS 39529*

National Aeronautics and
Space Administration

Stennis Space Center
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STENNIS SPACE CENTER TEST FACILITIES CAPABILITIES HANDBOOK

1.0 INTRODUCTION [5,14]*

The John C. Stennis Space Center (SSC) is located in Southern Mississippi near the Mississippi-Louisiana state line (see Figure 1.1-1). SSC is chartered as the National Aeronautics and Space Administration (NASA) Center of Excellence for large space transportation propulsion system testing. This charter has led to many unique test facilities, capabilities and advanced technologies provided through the supporting infrastructure. SSC has conducted projects in support of such diverse activities as liquid, and hybrid rocket testing and development; material development; non-intrusive plume diagnostics; plume tracking; commercial remote sensing; test technology and more. On May 30, 1996 NASA designated SSC the lead center for rocket propulsion testing, giving the center total responsibility for conducting and/or managing all NASA rocket engine testing. Test services are now available not only for NASA but also for the Department of Defense, other government agencies, academia, and industry.

This handbook was developed to provide a summary of the capabilities that exist within SSC. It is intended as a primary resource document, which will provide the reader with the top-level capabilities and characteristics of the numerous test facilities, test support facilities, laboratories, and services.

Due to the nature of continually evolving programs and test technologies, descriptions of the Center's current capabilities are provided. Periodic updates and revisions of this document will be made to maintain its completeness and accuracy.

1.1 History [5,12]

Selected in October 1961, the Mississippi Test Facility (originally part of the Marshall Space Flight Center), later renamed the National Space Technology Laboratories and known today as the John C. Stennis Space Center, offered ample land for construction of large test facilities with water access for shipping rocket stages and barge loads of propellants. Located in southwest Mississippi near the Mississippi-Louisiana border [approximately 45 miles (mi) from New Orleans, Louisiana], the Center is in a remote, nearly uninhabited area that provides the separation from surrounding communities that is required for test operations. A 13,500-acre fee area contains the facility infrastructure and test facilities for conducting large rocket tests. A 125,327-acre buffer zone, surrounding the fee area, provides an acoustical buffer and a barrier to community encroachment. Refer to Figure 1.1-1 for SSC's regional map.

* References are identified in the section headings. Bracketed numbers refer to reference documents and the numbers in parentheses refer to reference drawings, both of which are listed at the end of this handbook.

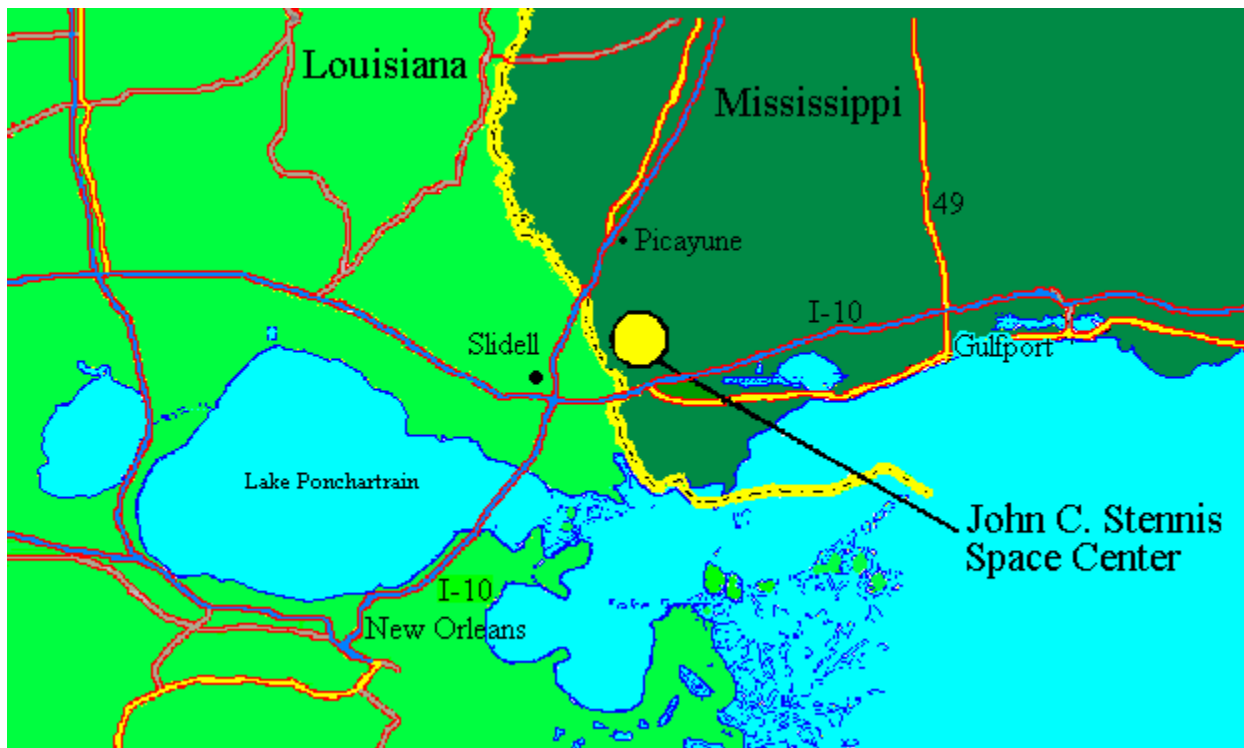


Figure 1.1-1 SSC Regional Map

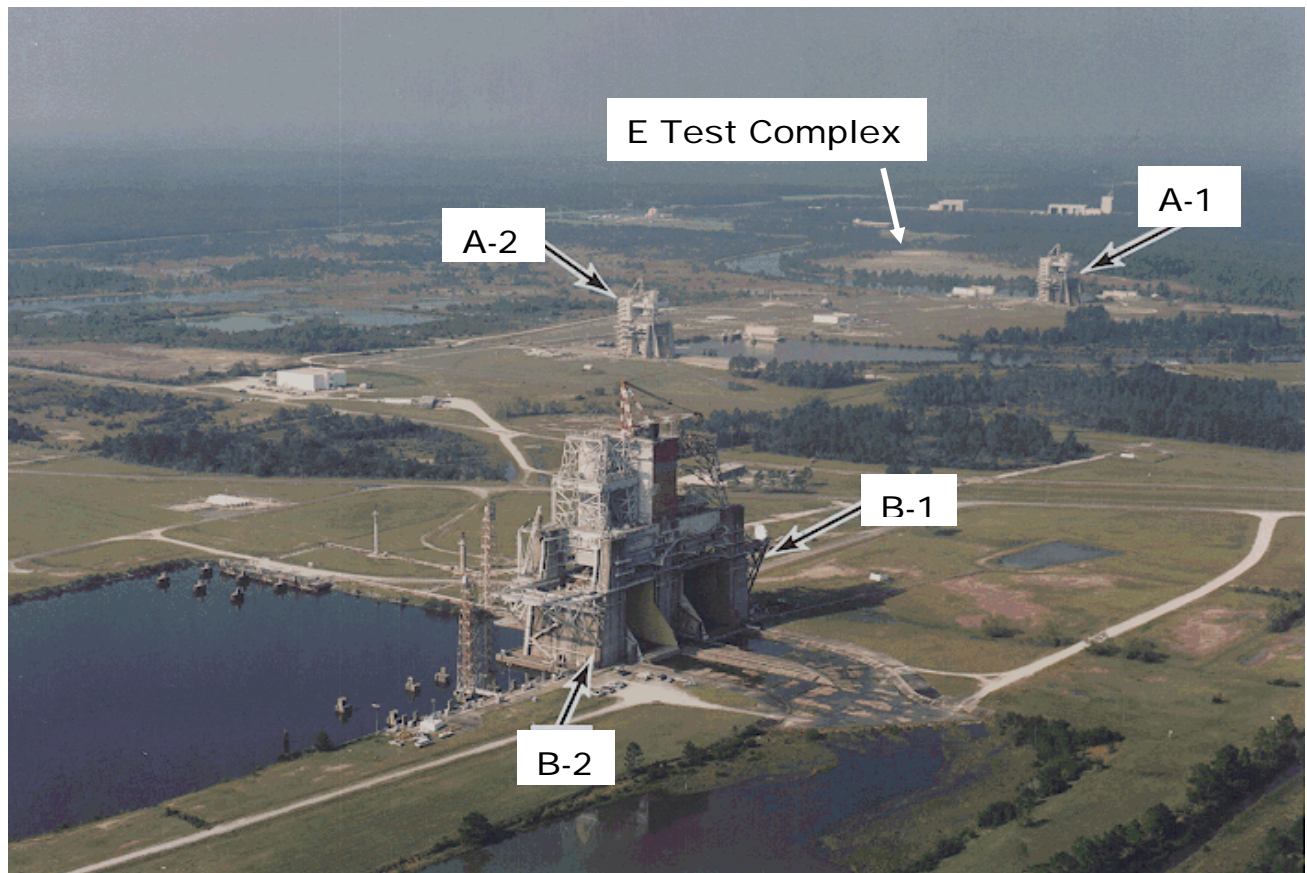
1.2 Background [5]

Initially established as a national testing center for flight certifying all first and second stages of the Saturn V “Moon Rocket” for the Apollo manned lunar landing program, Stennis Space Center conducted its first static firing on April 23, 1966, and continued testing into the early 1980’s. Then, in June 1975, SSC conducted the first test firing of the Space Shuttle Main Engine (SSME). Since then, as the Space Shuttle became an operational, First Generation Reusable Launch Vehicle, SSC has continued testing the SSME. Various improvements and enhancements have been tested which support the evolution of the Space Shuttle. In the late 1980s/early 1990s, several national propulsion development programs, among them the joint DoD/NASA Advanced Launch System (ALS)/National Launch System (NLS) Programs, the Advanced Solid Rocket Motor (ASRM) Program, and the National Aerospace Plane (NASP) Program, made large investments in ground test infrastructure and capability. One of the results was the construction, activation, and use of the “E” Complex, a major enhancement of the nation’s ground test capability. As a result, the E-1, E-2, and E-3 test stands have provided a wide range of test services from small engine systems (~100 lbf thrust) to the large engine systems (650K lbf thrust), from the component level (preburner or gas generator) to the integrated system (rocket engine) level, and from small commercial customers to multi-company, multi-agency consortia. In addition to its principal mission, SSC has evolved into a multidisciplinary laboratory comprised of other resident federal and state agencies, engaged in space, environmental and national defense programs. NASA, and the other resident agencies share common facilities, services, and

capabilities so each may accomplish its own mission in a more efficient and cost-effective manner. SSC has been a leader in the development and improvement of this operationally efficient concept.

1.3 Test Experience

The role of SSC is to provide, maintain, manage, and operate unique test facilities and the related capabilities required for development and acceptance testing and certification of rocket propulsion systems and subsystems. An overview of SSC's test experience is provided in the following sections.



SSC Test Complex

1.3.1 Apollo Saturn V First Stage [16,21]

The Apollo Saturn V First Stage (S-IC) was powered by five F-1 rocket engines capable of a 7.5-million-pound (M-lb) thrust at sea level. The stage was a liquid propellant booster using RP-1 as fuel and liquid oxygen (LOX) as the oxidizer, burning 15 tons of propellant per second. First stages were static fired in the B-2 test position of the "B" Dual Position Test Stand for acceptance testing from March 1967 through September 1970. Fifteen S-IC static firings were conducted for a cumulative duration of approximately 1,875 seconds.



Saturn V First Stage is lifted into the B-2 Test Stand

1.3.2 Apollo Saturn V Second Stage [18,22]

The Apollo Saturn V Second Stage (S-II) consisted of five J-2 rocket engines capable of developing a 1.15-M-lb thrust at altitude. The stage was tested at sea-level conditions, where an 812,500-lb thrust was produced, using liquid hydrogen (LH₂) as fuel and LOX as the oxidizer. The first rocket static test firing at SSC was an all-systems test model, the S-II-T, and fired in April 1966.

The S-II test program was conducted in the "A" Test Complex's A-1 and A-2 single-position test stands. Fifteen flight stages were static fired for acceptance through October 1970. In all, twenty-seven S-II static firings were conducted for a cumulative duration of approximately 7,106 seconds.



Saturn V Second Stage is lifted into the A-2 Test Stand

1.3.3 Space Shuttle Main Engines

SSME testing began with the first static test firing in May 1975. The SSME flight acceptance testing is currently carried out at SSC to support NASA's Space Transportation System (STS). The SSME develops a 375,000-lb thrust at sea level at a 100% rated power level. At one time, three test stands at SSC were testing SSMEs: A-1 at sea level conditions, and both A-2 and B-1 at simulated altitude conditions.

SSME tests are now conducted on the A-1 and A-2 test stands. A total of 2,600 static firings were conducted through the year 2003 for a cumulative run duration of approximately 1,000,000 sec. The longest SSME test firings exceeded 2,000 sec. in duration.

1.3.4 Space Shuttle Main Propulsion Test Article (MPTA)

The Space Shuttle MPTA simulated the Space Shuttle main propulsion system. It consisting of three SSME rocket engines, capable of developing a 1.125-M-lb thrust at sea level (100% rated power level). The MPTA static test firings were conducted from April 1978 through January 1981. Eighteen test firings were conducted for a cumulative run duration of approximately 3,775 seconds, and were conducted in the B-2 position of the "B" Test Complex dual test stand.

1.3.5 Component Testing

Since initial construction in the late 1980's, various test facilities have provided test services to an increasing number of test programs and test customers.

E-1 Test Facility began its first service testing commercial gaseous and/or liquid oxygen-hybrid rocket motors (1,000 to 10,000 lbs thrust). E-2 Test Facility began service providing research and development testing of prototype hydrogen fuel tanks for the NASP Program, as well as testing of prototype "multi-lobe" tanks for the Reusable Launch Vehicle (RLV) Program. The E-2 tank testing took advantage of pressurant and propellant systems in place, as well as added hydraulic loading capability, to test the tanks. In order to provide test service to small test articles with certain pressurants and propellants, the E-3 Test Facility was developed in the 1990's. Hybrid rocket motor testing was conducted in Cell 1, with test article thrust ranging up to approximately 60K lbf. Cell 2 was developed in the late 1990's, providing the nation's most capable ground test facility for testing high concentration hydrogen peroxide/hydrocarbon fueled rocket engine components and systems.



E-1 Test Facility



E-2, Cell 1



E-2, Cell 2



E-3

1.3.6 Commercial Rocket Engine Component, Engine System, and Booster/Stage Testing

After the ground work was effectively established with the commercial hybrid rocket motor and other commercial test projects in the E-Complex in the mid 1990's, agreements were reached with various commercial companies to expand testing into the A and B Test Complexes. The X-33 prototype vehicle for the RLV Program tested the Aerospike rocket engine on the A-1 test stand, with testing continuing through September 2001. Linear Aerospike engine technology was tested, along with other advanced technologies such as Electro-Mechanical Actuators (EMAs). A long-term agreement was reached to allow testing of the commercial RS-68 rocket engine, a large, cryogenic, hydrogen/oxygen rocket engine, on the B-1 test position. A commercially funded modernization provided two test positions on the B-1 test position. The MC-1 rocket engine (formerly known as the FASTRAC engine) was tested on the B-2 test position, in a horizontal mode as well as in a vertical mode on the Propulsion Test Article-1 (PTA-1). Following MC-1 testing, the Common Booster Core (CBC) test article in the Delta IV Program, one of the Evolved Expendable Launch Vehicles (EELV), was tested in the B-2 test position.

1.3.7 Evolution of SSC into a Multi-Customer Environment

In summary, the number and variety of test projects accomplished at the Stennis Space Center began rapidly expanding in the first half of the 1990's. What historically had been a world-class rocket engine/stage test center dedicated to a single test program, such as the Apollo/Saturn S-IC and S-II stages, and then the Space Shuttle Main Engine/Main Propulsion Test Article, had evolved into a multi-project, multi-program test center. Where the Test Customer had been another NASA Field Center, test customers had become not only other NASA Field Centers, but also other U. S. Government organizations, as well as the Commercial Rocket Propulsion and Space Launch Industry. Then, in 1996, SSC was designated NASA's Lead Center for Rocket Propulsion Testing. By the end of the 1990's and in the year 2000, all of SSC's test stands had active test projects for the first time in the history of SSC.

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2.0 NASA TEST OPERATIONS

Test operations are managed, conducted and/or supported, as applicable, in accordance with all applicable project, operations, safety, and quality requirements. The following sections define the directorates within NASA that support test projects.

2.1 Introduction

The Engineering and Science Directorate (E&S) is responsible for ensuring the adequate implementation of the test requirements of each test project. Project Management is provided by the Project Directorate. E&S provides for management of the test facilities and operations required for the testing of propulsion systems, subsystems, components, and related propulsion technologies. To accomplish its management role, E&S performs the functions of, System Engineering, Operations, and Test Support.

In addition to E&S, the Safety, Reliability and Quality Assurance (SR&QA) Office is involved in all projects, as applicable, to ensure product assurance and test safety requirements are satisfied. The SR&QA Office provides an independent review capability reporting to the Center Director as well as an in-project support advisory staff as applicable.

2.2 Project Management

The Project Management Directorate is the lead organization and primary point of contact, both internal and external to SSC, for the management of the testing project activities at SSC. A Project Manager is assigned to coordinate and communicate between the customer and other SSC organizations.

This office performs Proposal Development for the customer prior to acceptance and writing a Customer Agreement (CA). Once the CA is signed, the PM does Project Plan Development for test article handling and testing, followed by Requirements and Earned Value Management during operations. Requirements are captured in a Project Requirements Document (PRD). The PRD is the primary source of requirements by which all other sub-level documents and activities are developed.

Once test requirements are complete, the Project Manager performs a Project Closeout reflecting results of customer requirements. Finally, a Lessons Learned report is written to record observations during the test program.

2.3 Systems Engineering

The Systems Engineering & Integration Division of E&S provides the engineering management necessary to ensure that the test facilities and the systems design fulfill the test requirements and safe operations for those test programs assigned to SSC. In this management role, it provides the proper test facility design requirements and

incorporation of the test program requirements. Detailed test procedures are reviewed for compliance with program requirements. Support may be provided in the case of non-compliance to ensure that full compliance or acceptable modification of requirements is accomplished. Finally, test requirements are provided to the appropriate test operations organization.

2.4 Design and Analysis

The Design and Analysis Division of E&S provides mechanical and component design, electrical design, and system analysis and modeling to test projects. The group provides design engineering support to integrate construction, installation, and activation of test critical systems.

2.5 Test Operations

Carried out by the Operations Division of E&S, Test Operations includes the managing, directing, and safe performance of all test operations accomplished at SSC, by performing component, subsystem, and system level testing. It also ensures facility modifications, trouble-shooting, maintenance, calibration, repair, and retest for test programs. Other operations such as test article and support equipment assembly and handling are also provided as required by a test customer.

2.6 Test Support

The test support function is provided by the Business & Facility Management within E&S. This support entails the planning and establishment of requirements for the operation, maintenance, and management of the on-line support facilities and supporting elements. The support elements include providing required pressurants, propellants, industrial water, electrical power, maintenance, work control, and systems engineering support. The expertise for the maintenance and operation of supporting cryogenics, propellants, pressurants, high-pressure (HP) water, and electrical power systems is also provided as required. Test support is provided for design of support systems, design reviews, and test support facility configuration baselining. This division also addresses advanced automation and information technologies deployed throughout the test complexes.

3.0 PROPULSION TEST FACILITIES

SSC maintains full-scale rocket engine/motor test facilities, component and small engine test facilities and a materials test facility. All of these facilities are described in this section.

The "A" Test Complex and the "B" Test Complex accommodate large test stands sufficient for full-scale, liquid propellant rocket engine and system testing. For additional capability information for A or B Complex, please contact the Rocket Propulsion Test Program Office (contact information is on the Preface page) in order to get in contact with the Facility Manager associated with each of these test stands. Located within the E-Complex are three test facilities: E-1, E-2, and E-3. The E-1 facility has 3 test cells that provide ultra high pressure (up to 15,000 psi) testing capability for large-scale propulsion programs. E-2 has similar capability for intermediate sized component and engine test programs. The E-3 facility is capable of performing small and subscale engine/component testing. This facility can also test intermediate size engines in the horizontal position. For additional capability information for E-1, E-2, or E-3, please contact the Rocket Propulsion Test Program Office (contact information is on the Preface page) in order to get in contact with the Facility Manager associated with each of these test stands. Please also refer to the Facility Capability Document that is associated with each test stand in E-Complex. These documents are only available to NASA employees and NASA Contractor employees. The high-level capabilities associated with each of these facilities are described in the following sections.

3.1 "A" Test Complex [6,8](85,96-98)



A-1 Test Stand



A-2 Test Stand

The "A" Test Complex consists of two single-position, vertical-firing test stands designated A-1 and A-2. Each test stand is capable of static firing a test article up to 33 ft in diameter. Each test stand was designed for a maximum dynamic load of 1.1 M-lb vertical (up), 1.7 M-lb vertical (rebound), and 0.7 M-lb (horizontal). Both the A-1 and A-2 test stands are in current/recent operation; thus, the capabilities described at the

subsystem level may reflect configurations specific to a particular test program. Test configurations for the test stands have consisted of full flight stage and main propulsion system (ascent vehicle), and single engine testing at sea level and altitude simulation.

The A-1 and A-2 test stands are supplied with cryogenic fluids, gaseous hydrogen (GH_2) and inert gases, industrial water, and the electrical power necessary for test operations. LH_2 and LOX are supplied to the stands from cryogenic transportation barges. LH_2 and LOX are supplied to the test article from on-stand run tanks (simultaneous resupply from barge to run tank is possible during extended duration test operations). GH_2 is provided as a pressurant for the LH_2 run tank systems. Gaseous nitrogen (GN_2) is provided as a pressurant for the LOX run tank systems.

The A-1 and A-2 test stands are supplied with GH_2 and inert gases from gas storage batteries common to both test stands. The stands are operated from a common Test Control Center (TCC) configured with separate A-1 and A-2 control systems. Each stand is equipped with a derrick, lifting crane (75 tons, down-rated to 37.5 tons, with a 5-ton jib crane). The cranes are currently downmoded and are not in use. Additional information relating to the "A" Test Complex is contained in the following sections.



Barge being tranfered from A-1

3.1.1 Liquid Oxygen Propellant System [19,24](72)

The LOX dock and transfer systems at the A-1 and A-2 test stands provide LOX storage and transfer before, during, and after testing. Each test stand is equipped with a vacuum-jacketed (VJ) LOX run tank. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	Vessel Description	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-108-LO	A-1 Run Tank	250 (ullage)	250 (ullage)	40,000
V-105-LO	A-2 Run Tank	250 (ullage)	250 (ullage)	40,000

Table 3.1.1 A-Complex LOX Propellant Subsystem

LOX propellant subsystem capabilities follow:

- a. Docking facilities for two barges per stand and all shore-to-barge interface accessories, including flexible hoses at the main fill manifolds.
- b. A 10 inch (in.) diameter LOX transfer line from barge dock to test stand, including 40 micron (μ) filtering system; MDWP is 375 pounds per square inch gauge (psig).
- c. A 12 in. diameter LOX supply line from run tank to test article; MDWP is 250 psig.
- d. A 12 in. diameter LOX dump line rated at 4220 gallons per minute (gal/min). This line transfers LOX to the LOX dump pit during chilldown bleeds and emergency situations.
- e. A dockside, deluge-water piping system supplying industrial water at 5,000 gal/min and 215 psig.

3.1.2 Liquid Hydrogen Propellant System [19,24] (12, 13, 17, 61, 62, 73, 82-84, 100)

The LH₂ dock and transfer systems at the A-1 and A-2 test stands provide LH₂ storage and transfer before, during, and after testing. Each test stand is equipped with

a VJ LH₂ run tank. Relevant data for the existing pressure vessels is presented in the table on the next page.

Vessel Locator Number	Vessel Description	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-107-LH	A-1 Run Tank	66.5 (ullage)	50 (ullage)	110,000
V-104-LH	A-2 Run Tank	66.5 (ullage)	50 (ullage)	110,000

Table 3.1.2 A-Complex LH₂ Propellant Subsystem

LH₂ propellant subsystem capabilities follow:

- a. Docking facilities for two LH₂ barges per test stand and all shore-to-barge interface accessories, including flexible hoses at the main fill and vent manifolds.
- b. A minimum 8 in. diameter, VJ LH₂ transfer line from barge dock to test stand rated at 70 psig, including a 200 μ filtering system.
- c. A 12 in. diameter, VJ LH₂ supply line from run tank to test article, with maximum operating pressure of 65 psig.
- d. A 12 in. diameter, LH₂ barge, H₂ vent line to flare stack for LH₂ barge boil-off.
- e. A 24 in. diameter, test stand, H₂ vent line to flare stack for run tank LH₂ boil-off and line purge venting.
- f. A dockside, deluge-water piping system supplying industrial water at 8,000 gal/min, and 215 psig.

3.1.3 Gas Supply Systems [19,24]

The high-pressure, inert-gas battery in the "A" Test Complex contains air, helium (He), and nitrogen (N₂) gases. A separate gas battery is utilized for GH₂ storage. Gas batteries are common to both test stands, and they function as accumulators that are resupplied by cross-country gas transfer from the High Pressure Gas Facility (HPGF). Helium, nitrogen, and hydrogen gas pressures are regulated in a Pressure Reducing Area (PRA) at the base of each test stand. Air system pressure is not regulated prior to reaching the test stands.

3.1.3.1 Air Supply System (47-50,70,71,80,81)

The HP air storage, in the "A" Test Complex gas storage battery, consists of one HP vessel containing missile-grade air. Relevant data for the existing pressure vessel is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 2800 psig, 70 °F (scf)
V-096-HA	3,750	2,879	950	176,802

Table 3.1.3.1 A-Complex HP Air Storage Capacity

Design and operating characteristics of the HP air transfer systems are:

- a. A 3 in. diameter transfer line from HPGF to Valve Pit 5 (VP-5); with operating pressure of 2,800 psig and allowable pressure drop of 200 psi, MDWP is 3,700 psig
- b. A 2 in. diameter transfer line from VP-5 to VP-15; with an operating pressure of 2,800 psig and allowable pressure drop of 200 psi, MDWP is 3,700 psig.
- c. A 1 ½ in. diameter transfer line from VP-15 to "A" Test Complex gas storage battery; with operating pressure of 2,800 psig and allowable pressure drop of 200 psig, MDWP is 3,700 psig
- d. A 2 in. diameter transfer line from "A" Test Complex gas storage battery to A-1 and A-2 test stands; with operating pressure of 2,800 psig and allowable pressure drop of 200 psig, MDWP is 3,500 psig.

3.1.3.2 Helium Supply System (42-45,66,67,76,77)

The HP gaseous helium (GHe) storage at the "A" Test Complex gas storage battery consists of one HP vessel. Relevant data for the existing pressure vessel is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 3000 psig, 70 °F (scf)
V-101-HE	6,300	4,753	1,500	279,996

Table 3.1.3.2 A-Complex GHe Storage Capacity

Design and operating characteristics of the HP GHe transfer systems are:

- a. A 1 ½ in. diameter transfer line from HPGF to VP-7; with operating pressure of 3,000 psig, MDWP is 6,300 psig
- b. A 1 ½ in. diameter transfer line from VP-7 to A-2 Pressure Reducing Area (PRA); with operating pressure of 4,000 psig, MDWP is 6,300 psig
- c. A 4 in. diameter transfer line from A-2 PRA to GHe gas battery and A-1 PRA; with operating pressure of 4,000 psig, MDWP is 6,000 psig
- d. A 3 in. diameter transfer line from A-2 PRA to A-2 test stand; with operating pressure of 3,000 psig and allowable pressure drop of 400 psig, MDWP is 3,700 psig
- e. A 3 in. diameter transfer line from A-1 PRA to A-1 test stand; with operating pressure of 3,000 psig and allowable pressure drop of 400 psig, MDWP is 3,700 psig.

3.1.3.3 Nitrogen Supply System (32-35,39,63-65,74,75)

The HP GN₂ storage in the "A" Test Complex gas storage battery consists of four HP vessels. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (ft ³)	Water Volume	Storage at 4400 psig, 70 °F (scf)
V-068-GN	6,300	4,500	1,500	393,642
V-082-GN	6,300	4,576	1,500	393,642
V-097-GN	6,300	4,578	1,500	393,642
V-100-GN	6,300	4,678	1,500	393,642

Table 3.1.3.3 A-Complex GN₂ Storage Capacity

Design and operating characteristics of the HP GN₂ transfer systems are:

- a. A 4 in. diameter transfer line from HPGF to A-2 PRA; with operating pressure of 4,400 psig and allowable pressure drop of 100 psig, MDWP is 6,300 psig
- b. An 8 in. diameter transfer line from A-2 PRA to GN₂ gas battery and A-1 PRA; with operating pressure of 4,400 psig and allowable pressure drop of 100 psig, MDWP is 6,300 psig

- c. A 6 in. diameter transfer line from A-2 PRA to A-2 test stand; with operating pressure of 3,000 psig and allowable pressure drop of 100 psig, MDWP is 3,000 psig.
- d. A 6 in. diameter transfer line from A-1 PRA to A-1 test stand; with operating pressure of 3,000 psig and allowable pressure drop of 100 psig, MDWP is 3,000 psig.

3.1.3.4 Hydrogen Supply System (10-12,14-16,27,68,69,78,79)

The HP GH₂ storage area at the "A" Test Complex consists of four HP vessels. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft ³)	Storage at 3000 psig, 70 °F (scf)
V-066-GH	5,000	—*	1,250	226,963
V-071-GH	5,000	—*	1,250	226,963
V-219-GH	5,000	5,000	600	108,942
V-223-GH	5,000	5,000	600	108,942

*Not in Service

Table 3.1.3.4 A-Complex GH₂ Storage Capacity

Design and operating characteristics of the HP GH₂ transfer systems are:

- a. A 2 in. diameter transfer line from HPGF to A-2 PRA; with operating pressure of 3,000 psig and allowable pressure drop of 200 psig, MDWP is 6,000 psig
- b. A 2 in. diameter transfer line from A-2 PRA to GH₂ gas battery and A-1 PRA; with operating pressure of 3,000 psig and allowable pressure drop of 175 psig, MDWP is 6,000 psig
- c. A 1 ½ in. diameter transfer line from A-2 PRA to A-2 test stand; with operating pressure of 3,000 psig and filtered to 10 µ, MDWP is 3,700 psig
- d. A 1 ½ in. diameter transfer line from A-1 PRA to A-1 test stand; with operating pressure of 3,000 psig and filtered to 10 µ, MDWP is 3,700 psig

3.1.3.5 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the A-Complex.

3.1.4 Water Supply System [4]

Water for the "A" Test Complex is supplied from the High Pressure Industrial Water (HPIW) facility at a pressure of 215 psig, through a 75 in. diameter water line, at an operating flow rate of 212,000 gal/min. At the "A" Test Complex, the 75 in. diameter line splits into two 66 in. diameter lines, one supplying A-1 and the other supplying A-2.. See section 4.3.1 for additional information related to HPIW support operations.

3.1.5 Electrical Power Distribution [4](51)

Electrical power is distributed to the entire Test Complex by two, 13.8 kilovolt (kV) feeder circuits from the SSC Main Substation. At the "A" Test Complex, circuits 11 and 21 source double-ended, 480 volt (V) substations at the A-1 and A-2 test stands, Building 4995, and the "A" Test Control Center (A-TCC), all of which step 13.8 kV down to 480 V. Feeder circuit breakers then distribute the 480 V to lighting panels, Motor Control Centers (MCCs), transformers, 28 volt direct current (VDC) rectifiers, etc., for utilization. Control power is provided by redundant 28 VDC rectifiers with battery backup should the 480 V fail. All safety-critical control devices are powered with 28 VDC to ensure that a test can be terminated safely if there is a power failure.

During engine testing, the test conductor may request that the Emergency Generators (refer to Section 4.3.2) supply power to the Test Complex to avoid a test interruption should utility power fail.

3.1.6 Data Acquisition [15]

The A Complex TCC is the central data collection and processing facility receiving engine, pre-test, and post-test data from the test article and the A test facility. Data acquisition consists of a low speed and a high speed system. A-1 and A-2 each have a low speed system. One high speed system is shared between the stands.

The low speed system consists of 512 analog input channels and 64 discrete channels acquired at rates up to 250 SPS. The signal conditioners and redundant A/D front ends reside on level 6 of each test stand. Test data is recorded locally and transmitted on an isolated network to the TCC where redundant data loggers acquire, store, and post-process the test data from the primary front end. The secondary front end data is recorded on a separate logger 24 hours a day, 7 days a week. It records up to 50 SPS. Additionally there is a stand alone events recorder consisting of 736 discrete inputs that records up to 250 SPS. Redundant front ends for the events system also reside on level 6 of each test stand. Data is recorded locally and transmitted over the same isolated network to an events logger. Real-time display of data in the TCC is provided in both tabular form as well as graphical trend.

The high speed system consists of 128 analog input channels. Data is recorded at a maximum sample rate of 100,000 SPS. The system is shared between A-1 and A-2 using patch panels.

Redline monitoring is accomplished by taking one of the unfiltered outputs from the signal conditioners and patching to a 128 channel redline system composed of Programmable Logic Controllers (PLC's) in the TCC.

3.1.7 Test Control Center[15]

The A-TCC is the central point for control of the A-1 and A-2 Test Stand Facilities. The A-1 and A-2 facilities are each supported by separate PLC systems that control both digital and analog functions on the test stand and its auxiliary systems such as propellant barge docks, etc.

Manual and automatic functions are controlled by these PLC's. These include control of valve states, propellant tank pressurization, propellant transfer from barges to the run tanks, test sequencing and timing, facility cutoff functions and the numerous other functions required to set up and perform a test as well as secure the test article and facility post test.

A backup system is in place to safely secure the test article and facility in the event of a catastrophic failure that may render the PLC inactive during a test.

The PLC facility control system is capable of manipulating both discrete (on - off, open-close) signals and analog (pressure, temperature, etc) signals. The system employs, but is not limited to, approximately 450 discrete inputs from the facility, 250 discrete outputs to the facility, 60 analog inputs from the facility and 20 analog outputs to the facility. This system is computer based and its functional logic is easily modified via a graphical programming application. During operation the PLC performs a complete repetition of its logic in approximately 15 milliseconds, (67 repetitions per second).

Test personnel control the functions of the PLC system via graphical workstations running specialized HMI programs. Each workstation utilizes a cluster of computer screens displaying menu selectable graphical representations of the test stand facility systems. Data from instrumentation systems is also displayed on these screens to allow test operations personnel to have an integrated view of system performance. Various functions such as opening or closing a valve, increasing a pressure, starting the automatic test sequencer, etc are controlled by pointing and clicking a mouse cursor on the desired object on these screens. Feedback is provided to the screens to indicate statuses such as valve open or closed by changes of color or other positive identifications.

Test personnel use closed circuit television (CCTV) monitors for test stand and test article surveillance. Each stand has 4 high speed video cameras and up to 16 low speed video cameras. Audio communication among test personnel is accomplished through the use of headsets and 2-way radios.

3.2 "B" Test Complex [7,17](95)(99)

The "B" Test Complex consists of a dual-position; vertical, static-firing test stand designated the B-1/B-2 test stand. Each test position is capable of static-firing test articles up to 33 ft. in diameter. Each position is capable of supporting a maximum dynamic load of 11.0 M-lb vertical (up), 8.5 M-lb vertical (rebound), and 6.0 M-lb (horizontal) [Note: Current configuration does not support maximum design limits]. The B-1 test position was configured for single engine testing for the SSME program in the late '80s. It is currently in operation with dual firing positions (B1A and B1B) for RS-68 testing, thus, the capabilities described at the subsystem level reflect configurations specific to that test program. The B-2 test position tested the first state of the Saturn V rocket as well as the MPTA for the space shuttle program. Testing at B-2 for the Delta IV Common Booster Core Program was completed in fiscal year 2001. The capabilities described at the subsystem level reflect configurations specific to that test program.

The B-1/B-2 test stand is capable of being supplied with LOX and LH₂ cryogenic fluids, GH₂, and inert gases; industrial water; and the electrical power necessary for test operations. LH₂ and LOX are supplied to the stands from cryogenic transportation barges and supplied to the B-1 test position from on-stand run tanks. (Resupply from barge to run tank is possible during test operations for extended duration testing.) GH₂ is provided as a pressurant for the LH₂ run tank system. GN₂ is provided as a pressurant for the LOX run tank systems.



B-1/B-2 Test Stand

The B-1/B-2 test stand is supplied with GH_2 and inert gases from "B" Test Complex gas storage batteries. The test stand's two positions are operated from a common TCC configured with separate B-1 and B-2 control systems. Both positions have separate Dedicated Data Acquisition and Control Systems (DACs). The B-1/B-2 test stand is equipped with a 200-ton, main derrick, lifting crane, with a 20-ton jib crane and a 175-ton auxiliary derrick, lifting crane (currently inactive). Additional information relating to the "B" Test Complex is contained in the sections that follow.



LOX Barge

3.2.1 Liquid Oxygen Propellant System [19,24](86,93)

Before, during, and after testing, the LOX dock and transfer systems at the "B" Test Complex provide LOX storage and transfer for both the B-1 and B-2 test positions. The B-1 test position is equipped with a VJ LOX run tank. B-2 is also equipped with a VJ LOX storage/transfer tank. Relevant data for the existing pressure vessels is presented in the table on the next page.

Vessel Locator Number	Vessel Description	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-150-LO	B-1 Run Tank	110 (ullage)	110 (ullage)	49,550
V-266-LO	B-2 Storage/Topping	146 (ullage)	135 (ullage)	28,000

Table 3.2.1 B-Complex LOX Propellant Subsystem

3.2.1.1 B-1 LOX Propellant Subsystem

- a. Dock facilities for three (3) LOX barges and all shore-to-barge interface accessories, including flexible hoses at the main fill manifolds. Two additional barge positions are available but have no piping or mooring devices.
- b. A LOX transfer line from the barge docks to the test stand. The line is comprised of 14 in. piping to another level then transitions to 10 in. A tee and manual shutoff valves are incorporated to configure the line for use at B-1 or B-2. The 10 in. line that feeds the B-1 run tank has a Y pattern 40 μ filter. MDWP of the transfer line is 275 psig.
- c. A LOX run line from the bottom of the run tank to the test positions. The line is 12 in. diameter from the tank and transitions to 16 in. diameter on another level. A Y with separate manually operated isolation valves is employed to feed each test position (B1A & B1B). Separate remotely operated prevalues and 800 micron strainers are include on each leg. MDWP of the run line is 275 psig.
- d. A minimum 18 in. diameter LOX dump line to deliver LOX to LOX dump pit during chilldown bleeds and emergency situations.
- e. A dockside, deluge-water piping system supplying industrial water at 70,000 gal/min, 215 psig.
- f. Gaseous Nitrogen purges are provided for throughout the LOX transfer systems via hand valves and remotely controlled solenoid valves.

3.2.1.2 B-2 LOX Propellant Subsystem

- a. B-2 test stand has a 28,000 gallon storage tank for transfer of LOX for topping off the test article tank. Tank has provisions for filling directly from propellant trailers.
- b. A topping line from V-266-LO another level where it ties into the primary LOX transfer line. The line is 4 in. diameter up a level then transitions to

3 in. Connection points with manual shutoff valves are present at docks 1 and 2. These points were employed by the MPTA and Apollo programs to connect small centrifugal pumps mounted on the LOX barges for slow fill of the test article. The CBC program provided slow fill to the test article by pressurization of V-266-LO. MDWP of the topping line is 220 psig although some of the older segments were designed for higher pressure. The system is capable of transferring LOX at a flow rate of 0 lb/s to 20 lb/s to the test stand.

- c. Transfer line piping from tee. Line terminates near the location of the test article and incorporates a tee type filter. MDWP is 275 psig.

3.2.2 Liquid Hydrogen Propellant System [19,24]

3.2.2.1 B Complex Propellant Subsystem

Before, during, and after testing, the LH₂ dock and transfer systems at the "B" Test Complex provide LH₂ storage and transfer for both the B-1 and B-2 test positions. The B-1 test position is equipped with a VJ LH₂ run tank. Relevant data for the existing pressure vessel is presented in the following table.

Vessel Locator Number	Vessel Description	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-151-LHB-1	Run Tank	66 (ullage)	66 (ullage)	90,000

Table 3.2.2.1 B-Complex LH₂ Propellant Subsystem

LH₂ propellant subsystem capabilities are as follows:

- a. Dock facilities for three LH₂ barges and all shore-to-barge interface accessories, including flexible hoses at main fill and LH₂ barge GH₂ vent manifolds.
- b. A 10 in. diameter, VJ, LH₂ transfer line from barge dock to dual-stand B-1/B-2 positions. A tee with separate shutoff valves at the base of the test stand provides flow to the B-1 or B-2 (B-2 valve is currently removed) position. Piping for the B-1 side runs from the base of the stand to the bottom of the LH₂ run tank and includes a shutoff valve and 200 μ filter. Piping for the B-2 side runs from the base of the stand and includes shutoff valves, bleed valves, a 200 μ filter, and a bypass leg with flow control valves to provide replenishment flow. MDWP is 70 psig.
- c. A LH run line from the bottom of the run tank to the test positions. The line is 12 in. diameter from the tank and transitions to 16 in. diameter immediately below the LH₂ tank valve. A Y with separate manually

operated isolation valves is employed to feed each test position (B1A & B1B). Separate remotely operated prevalves and 800 micron strainers are include on each leg. MDWP of the run line is 275 psig.

- d. A 12 in. diameter GH₂ vent system with a dedicated flare stack for venting boil off from the three LH₂ barge positions and boil off/purge flow from the transfer line.
- e. A H₂ vent system with a dedicated flare stack for the B-1 position. Piping is 10 in. and 8 in. diameter on the stand and transitions to 18 in. diameter at the base of the stand. Boil off from the LH run tank and bleed flow through the test article at B1A or B1B is vented through this system. Run duct and transfer line bleed, drain and relief valves discharge to this system also.
- f. A GH₂ vent system with a dedicated flare stack for the B-2 position. Piping is 18 in. diameter on the stand and transitions to 12 in. diameter at the base of the stand. Boil off from the test article would be vented through this system. Transfer line bleed, drain and relief valves discharge to this system also.
- g. A dockside, deluge-water piping system supplying industrial water at 12,500 gal/min, 215 psig.

3.2.3 GHe Spin Start System

A GHe spin start (HeSS) system at B-1 provides a high flow rate of GHe for engine start. System consists of two spherical vessels to provide a surge capacity of GHe at the test stand. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	Vessel Description	MDWP (psig)	Certified Pressure (psig)	Volume (ft³)
V-257-He	South HeSS Bottle	3000	3000	80
V-272-He	North HeSS Bottle	3000	3000	80

Table 3.2.3 GHe Spin Start System Storage Capabilities

GHe Spin Start system capabilities are as follows:

- a. 3 in. diameter schedule 80S piping from the two bottles to the flow control valve with shutoff valves at each bottle and on the main line. A regulator in this line reduces the pressure to 1850 psig max
- b. A hydraulically controlled flow control valve. Ancillary hydraulic system provides 2400 psig hydraulic for operation
- c. 3 in. diameter schedule 80S piping with shutoff and check valves from the flow control valve to the two test positions B1A and B1B.
- d. 3 in. diameter schedule 80S piping from the bottles to the B-2 position. (Valves and regulators have been removed)

3.2.4 Gas Supply Systems [19,24]

The HP inert-gas battery in the "B" Test Complex contains HPA, He, and GN₂ gases. A separate gas battery is utilized for GH₂. The gas batteries serve the B-1 and B-2 test positions and function as accumulators that are resupplied by cross-country gas transfer from the HPGF.

3.2.4.1 Air Supply System (91, 94)

The HP air storage at the "B" Test Complex inert gas storage battery consists of one HP vessel containing missile-grade air. Relevant data for the existing pressure vessel is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 4400 psig, 70 °F (scf)
V-146-HA	3,750	2,917	950	176,802

Table 3.2.4.1 B-Complex HP Air Storage Capability

Design and operating characteristics of the HP Air transfer systems are:

- a. A 3 in. diameter transfer line from HPGF to VP-5; with operating pressure of 2,800 psig and allowable pressure drop of 200 psig, MDWP is 3,700 psig.
- b. A 2 in. diameter transfer line from VP-5 to VP-6; with operating pressure of 2,800 psig and allowable pressure drop of 200 psig, MDWP is 3,700 psig.

- c. A 1 ½ in. diameter transfer line from VP-6 to "B" Complex gas storage battery; with operating pressure of 2,800 psig and allowable pressure drop of 200 psig, MDWP is 3,700 psig.
- d. A 2 in. diameter transfer line from gas battery to B-1 and B-2 test position; with operating pressure of 2,800 psig and allowable pressure drop of 400 psig, MDWP is 3,700psig.

3.2.4.2 Helium Supply System (92)

The HP GHe storage at the "B" Test Complex inert gas storage battery consists of three HP vessels. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 3000 psig, 70 °F (scf)
V-144-HE	6,300	4,725	1,500	279,996
V-141-GHe	6,300	4,814	1,065	198,204
V-143-GHe	6,300	4,693	1,500	279,161

Table 3.2.4.2 B-Complex GHe Storage Capability

Design and operating characteristics of the HP GHe transfer systems are:

- a. A 1 ½ in. diameter transfer line from HPGF to VP-7; with operating pressure of 4,000 psig, MDWP is 6,300 psig.
- b. A 1 ½ in. diameter transfer line from VP-7 to "B" Complex gas storage battery; with operating pressure of 4,000 psig and allowable pressure drop of 200 psig, MDWP is 6,300 psig.
- c. A 3 in. diameter transfer line from gas battery to B-1 and B-2 test position; with operating pressure of 3,000 psig and allowable pressure drop of 300 psig, MDWP is 6,300 psig.
- d. Dual regulators to reduce supply on the test stand to 1500 psig. Regulators feed the master facility panel and other ancillary purge panels on the test stand.

3.2.4.3 Nitrogen Supply System (89-90)

The HP GN₂ storage at the "B" Test Complex inert gas storage battery consists of four HP vessels. Relevant data for the existing pressure vessels is presented in the table on the next page.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 4400 psig, 70 °F (scf)
V-225-GN	6,600	6,600	750	196,821
V-226-GN	6,600	6,600	750	196,821
V-231-GN	6,600	6,600	750	196,821
V-232-GN	6,600	6,600	750	196,821

Table 3.2.4.3 B-Complex GN₂ Storage Capability

Design and operating characteristics of the HP GN₂ transfer systems are:

- a. A 4 in. diameter transfer line from HPGF to VP-7; with operating pressure of 4,400 psig and allowable pressure drop of 100 psig, MDWP is 6,300 psig.
- b. A 3 in. diameter transfer line from VP-7 to "B" Test Complex GN₂ storage battery; with operating pressure of 4,400 psig, MDWP is 6,300 psig.
- c. An 8 in. diameter transfer line from "B" Test Complex GN₂ storage battery to test stand; with operating pressure of 4,400 psig and allowable pressure drop of 100 psig, MDWP is 6,300 psig.
- d. Pressure reducing area (PRA) at the base of the test stand with 4 high flow PCVs to regulate the stand supply to a maximum of 3400 psig. Normal operating pressure is 2500 psig.

3.2.4.4 Hydrogen Supply System

The HP GH₂ storage area at the "B" Test Complex consists of three HP vessels. Relevant data for the existing pressure vessels is presented in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 3000 psig, 70 °F (scf)
V-224-GH	5,000	5,000	600	108,942
V-227-GH	6,600	6,600	608.9	110,558
V-072-GH * (Rail-Car)	5,000	-----	2,500	453,925

* Not in service.

Table 3.2.4.4 B Complex GH₂ Storage Capability

Design and operating characteristics of the HP GH₂ transfer systems are:

- a. A 2 in. diameter transfer line from HPGF to Test Complex (tee joint to "A" and "B" Test Complexes); with operating pressure of 3,000 psig and allowable pressure drop of 200 psig, MDWP is 6,000 psig.
- b. 1 ½ in. diameter transfer line from Test Complex (tee joint "B" Test Complexes) to "B" Test Complex GH₂ storage battery; with operating pressure of 3,000 psig, MDWP is 3,200 psig.
- c. A 2 in. diameter transfer line from "B" Test Complex, GH₂ storage battery to test stand; with operating pressure of 3,000 psig and allowable pressure drop of 175 psig, MDWP is 4,400 psig.
- d. A shutoff valve and bypass regulator at the base of the test stand to maintain GH₂ pressure at less than 400 psig when test operations are not in progress.

3.2.4.5 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the B-Complex.

3.2.5 Water Supply System [4]

Water for the "B" Test Complex is supplied from the HPIW facility at a pressure of 215 psig, through a 96 in. diameter water line at an operating flow rate of 330,000 gal/min. See section 4.3.1 for the HPIW support operations.

3.2.6 Electrical Power Distribution [4](51)

Electrical power is distributed to the Test Complex by two, 13.8 kV feeder circuits from the SSC Main Substation. At the "B" Test Complex, circuits 11 and 21 source double-ended, 480 V substations at the B-1/B-2 dual test stand and at the "B" Complex TCC. Both main feeder circuits (circuits 11 and 21) are electrically separated using a "bus" tie breaker. This "bus" tie breaker is normally operated in the "open" position. Dedicated transformers for both circuits (circuits 11 and 21) are used to step the voltage down from 13.8 kV to 480 VAC. Feeder circuit breakers then distribute the 480 V to lighting panels, Motor Control Centers (MCCs), transformers, 28 VDC rectifiers, etc., for utilization. Control power is provided by redundant 28 VDC rectifiers with battery backup should the 480 V fail. The batteries are sized to carry the control power load for approximately 20 minutes in the event of a power failure (loss of 480 V input power to the rectifier). All safety-critical control devices (PLCs, relays, solenoid valves, etc.) are powered with 28 VDC to ensure that a test can be terminated safely if there is a power failure. During engine testing, the test conductor may request that the Emergency

Generators (see Section 4.3.2) supply power to the Test Complex to avoid a test interruption should utility power fail. During the use of Emergency Generators, the commercial power system is electrically separated from the test complex.

3.2.7 Data Acquisition [15]

The B Complex Test Control Center (TCC) is the central data collection and processing facility receiving engine pre- and post-test data from the test article and the B test facility. The B-TCC uses redundant loggers connected to an isolated network to acquire, store, and post-process test data. Test data is also recorded onto control computers that are located on the teststand near the data acquisition systems. Real time display of data is provided in both tabular form as well as graphical trend. Data can be displayed in engineering units and raw counts. The low-speed DAS has the capability of acquiring up to 592 (B-1) and 512 (B-2) analog input channels at a rate of 250 SPS each. The B1 RS68 program currently uses a DAS sample rate of 200 SPS. The current high speed data acquisition system (RACAL) has the capability of acquiring up to 128 channels at a sample rate of 100K SPS. The designated replacement high speed data acquisition system (Datamax) will contain 64 channels with a sample rate of 204.8K SPS. The new Datamax system is currently being operated in parallel with the heritage RACAL system. Transducers are interfaced to the facility data acquisition systems using electrical cables that are referred to as “drag on cables”. Patch panels are used to connect the current test stand to this low-speed DAS. Front-end signal conditioning and amplifiers for RTDs, thermocouples, strain gages, etc., are provided, as required, at the test stand. Redundant, non filtered signal outputs are patched to a separate computer system to provide red-line cutoffs for critical measurements. The B-1 test stand is presently certifying a PLC system to provide facility red-line protection. The PLC based system will have a capacity of 128 channels.

A modernization project upgraded and increased the capacity of the DACS in 1997. Test stands A-1, A-2, B-1, and B-2 have separate, dedicated systems with the capabilities listed in Table 3.2.7-1. These systems have a very low setup time, reconfiguration, and pretest/post test tasks.

1.	512 Channels of Low Speed Analog Data with signal conditioning and A/D Mux (B-1) 320 Channels of Low Speed Analog Data with signal conditioning and A/D Mux (B-2)
2.	128 Channels of Digital High Speed Analog Data recorded on Data Grade VHS tapes (B-1 only)
3.	High Speed Fiber optic data network between test stands and Test Control Centers (TCC)
4.	Automated system configuration, calibration, setup, and checkout procedures (B-1 only)
5.	Computer based Control System with Graphical User Interface for facility functions (B-1 only)
6.	NTSC Video in color and B/W/IR for test article and facilities (B-1 only)
7.	No high speed video capability

Table 3.2.7-1 Test Complex Data Acquisition and Control System Capabilities

The B Complex DAS has signal conditioning, filtering, amplification, and multiplexing to accommodate a channel capability of 592 channels (B-1) and 512 channels (B-2). The signal conditioning and data acquisition systems consist of low frequency (up to 250 SPS) and high frequency (100,000 SPS) channels with up to 128 channels for high frequency signals. The replacement high speed system will have 64 channels with a sample rate of 204.8K SPS. The B-1 and B-2 DAS also provides digital interfaces for the acquisition of discrete events. These channels are digitized and transmitted via fiber optics to the B-1 and B-2 control rooms in the B-TCC where they are recorded and displayed. Displays are provided in the Test Control Centers and on the Teststand for monitoring of channels and blue/redline limit checking. Currently, the B-2 Test Control Center, the B-2 data acquisition systems (low and high speed), the B-2 camera system, the B-2 facility redline system, and the B-2 data networks are not operational. It would take an extensive effort to bring these systems to a working configuration.

3.2.8 Test Control Center [15]

The B-TCC is a dual control room facility for the B-1 and B-2 test positions. This facility houses control system equipment and serves as the central command location for the test conductor and personnel, who are required to observe, monitor, supervise, and control test operations at the B-1 (or B-2, currently not operational) test position during a test firing. Each TCC area contains the following hardware: computer(s) for data collection; a facility control console with meters, indicator lights, and operating devices; low speed CCTV cameras, recorders, and monitors for test stand surveillance; audio communications; and real time and graphical display instrumentation system(s). Separate B-1/B-2 operated control systems monitor critical test functions and initiate corrective actions or terminate a test.

The B-1 control system consists of a facility control console with meters, indicator lights, timers, switches and dials for operation of facility systems. This is a 28 VDC system which incorporates relay logic and timers for sequencing of the facility valves during engine start and shutdown. 28 V power is supplied from redundant rectifiers at the test stand which have a battery back up systems for uninterruptible power.

The B-2 control system is a PLC based system with standard commercially available industrial PLC's communicating over a dedicated fiber optics network. The operator interface is accomplished with workstations running operator interface software for displaying system schematics, status, alarms and commands. Communication between the PLC's and the workstations is via fiber optics. This PLC based system also provides control of the LOX and LH₂ transfer systems for both B-1 and B-2. PLCs for this system are powered from the 28 V uninterruptible power supply at the test stand. The B-2 control system can be readily reconfigured to meet the requirements of the test article.

3.3 "E" Test Complex [1](56-59)

The E Test Complex consists of a high flow rate facility, high heat flux facility and a subscale test facility. The E-1 multi-cell test facility is a high flow rate facility capable of testing gas generator and preburner driven liquid oxygen/liquid hydrogen (LOX/LH₂) turbopump assemblies. It is also capable of testing a variety of combustion devices and other rocket engine components and sub-assemblies. The E-2 multi-cell test facility is a versatile test complex for developmental testing projects involving hot gas, cryogenic fluids, gas impingement, inert gases, industrial gas, specialized gases, hydraulics, and deionized and industrial water. The E-3 Test Facility is a versatile test complex that is available for component development testing of combustion devices, rocket engine components and small/subscale complete engines and boosters. Particularly unique is the established capability at E-3 to test components and rocket engines using high concentration (up to 98%) hydrogen peroxide. The facility has two test cells, Cell 1 is a horizontal test stand, which is capable of testing intermediate sized engines, and Cell 2 is a vertical test stand.

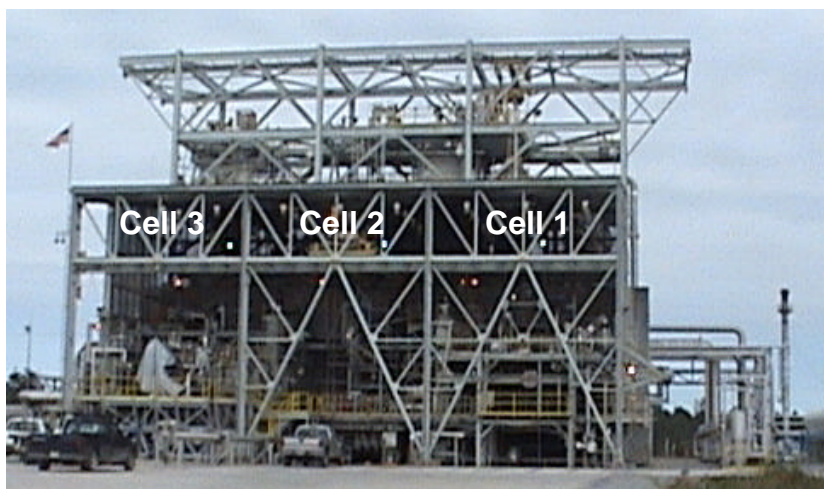
A Test Operations Building (TOB) houses the TCC (Test Control Center) for each of the three test facilities in the E Complex, test control and data acquisition equipment, general offices, and a component preparation area. The component preparation area will be used for assembly and maintenance work on test articles. The TOB will provide an environmentally controlled area for electronic equipment as well as an enclosed facility for personnel safety during testing. The TOB is designed to allow expansion of the data collection and evaluation areas into the component preparation area. Signal Conditioning Buildings (SCBs) are located near the test cells and house test control and data acquisition equipment.

3.3.1 E-1 Test Facility [25]

The E-1 Test Facility is a versatile test complex that is available for component development testing of combustion devices, turbopump assemblies, and other rocket engine components. Originally designed to test turbomachinery for the Advanced Launch System (ALS) and then the National Launch System (NLS) Programs, it has been modified several times. The facility has the capacity to deliver high flow rate propellants at high and low pressures. In addition, the facility is equipped to supply a wide range of supporting fluids. Data acquisition and control systems at E-1 have high capacities and are the state-of-the-art in number of channels and data storage.

The facility has three test cells capable of accommodating multiple programs at the same time. The test article structural supports in all three test cells have common interface arrangements. Each test cell is 30 ft. wide by 30 ft. deep by 26 ft. high. A structural blast wall separates the supporting test complex infrastructure from the test cells. Each test cell contains all of the support equipment, service connections, test instrumentation and safety equipment required to perform testing.

A 10-ton overhead bridge crane spans all three test cells and a 10-ton crane provides lifting capability to the facility behind the blast wall. The test cells are covered for protection from environmental elements.



E1 Test Stand

3.3.1.1 E-1 Cell 1

Cell 1 is primarily designed to test pressure-fed LOX/LH₂, LOX/RP-1, and hybrid combustion devices up to 750,000 lbf of horizontal thrust (1,500,000 lbf impulse load). A design modification has been completed which increases the horizontal thrust capability to 1.2 Mlbf and a vertical thrust of 600,000 lbf. The concrete modifications are complete, thrust structure modification to the test cell are in future plans. Currently, the high pressure LOX feed line and a high pressure LH₂ feedline are routed to Cell 1. Future plans call for two high pressure RP-1 feed lines and a low pressure RP-1 feedline to be routed to Cell 1. The following table outlines the existing and predicted future commodity supply capabilities for Cell 1.

Commodity	Pressure (psig)	Temperature (°R/°F)	Flow Rate (lbm/sec)	Supply Line (in.)	Existing/ Future
HP LOX	7,700	178 / -281	1800	12	<input checked="" type="checkbox"/> <input type="checkbox"/>
LP LH ₂ *	250	38 / -422	225	12	<input checked="" type="checkbox"/> <input type="checkbox"/>
HP LH ₂	7,750	75 / -385	205	12	<input checked="" type="checkbox"/> <input type="checkbox"/>
LP RP-1	300	540 / 80	1,050	12	<input type="checkbox"/> <input checked="" type="checkbox"/>
HP RP-1	7,800	540 / 80	1,050	12	<input type="checkbox"/> <input checked="" type="checkbox"/>
HP RP-1	8,000	540 / 80	50	3	<input checked="" type="checkbox"/> <input type="checkbox"/>

* Note: LP LH₂ Facility runline enters at Cell 2, STE piping can route to Cell 1.

** Note: Higher mass flowrates are possible with corresponding reduction in interface pressure.

Table 3.3.1.1 E-1 Cell 1 Commodity Storage and Supply Capabilities

3.3.1.2 E-1 Cell 2

Cell 2 is primarily designed to test LH₂ and LOX turbopump assemblies, either simultaneously or individually. The test article support structure for Cell 2 is designed for test articles weighing up to 30,000 lbs and generating up to 60,000 lbf thrust (120,000 lbf impulse) at angles up to 10° above horizontal. The following table outlines the existing and future commodity supply capabilities for Cell 2.

Commodity	Pressure (psig)	Temperature (°R/°F)	Flow Rate (lbm/sec)	Supply Line (in.)	Existing/ Future	
HP LOX	7,765	178 / -281	165	3	<input checked="" type="checkbox"/>	<input type="checkbox"/>
HP LOX	7,765	178 / -281	12	1	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LP LOX	295	165 / -294	1,220	12	<input checked="" type="checkbox"/>	<input type="checkbox"/>
HP LH ₂	7,750	75 / -385	90	8/6/4/8	<input checked="" type="checkbox"/>	<input type="checkbox"/>
HP LH ₂	7,750	75 / -385	2	1	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LP LH ₂	250	38 / -422	225	12	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LP RP-1*	300	540 / 80	1,050	12	<input type="checkbox"/>	<input checked="" type="checkbox"/>
HP RP-1	7,800	540 / 80	55	4	<input type="checkbox"/>	<input checked="" type="checkbox"/>

* Note: LP RP-1 Facility runline enters at Cell 1, STE piping can route to Cell 2.

Table 3.3.1.2 E-1 Cell 2 Commodity Storage and Supply Capabilities

3.3.1.3 E-1 Cell 3

Cell 3 is primarily designed to test LOX-rich turbopump assemblies and engine system assemblies. The test article support structure inside of Cell 3 is designed for test articles weighing up to 30,000 lbs and generating up to 60,000 lbf thrust (120,000 lbf impulse) at angles up to 10° above horizontal. The Test Article Support Structure (TASS) for Cell 3 engine system testing is designed for test articles weighing up to 15,000 lbs. Both the TASS and Thrust Takeout Structure (TTS) are designed for test articles generating up to 750,000 lbf thrust (1,500,000 lbf impulse) at angles up to 10° above horizontal. The table on the next page outlines the existing commodity supply capabilities for Cell 3.

Commodity	Pressure (psig)	Temperature (°R/°F)	Flow Rate (lbm/sec)	Supply Line (in.)
HP LOX	7,765	180 / -280	1,000*	2 @ 8
HP LOX	7,765	180 / -280	1.5	1
LP LOX	295	165 / -296	1,220	12
LP LH	335	39 / -421	250	12
HP LH ₂	7,750	61 / -399	30	3
HP LH ₂	7,750	61 / -399	0.5	1

* Note: Each 8" supply line provides up to 500 lbm/s.

Table 3.3.1.3 E-1 Cell 3 Commodity Storage Capabilities

3.3.1.4 Commodity Storage and Capabilities

The following table contains a complete listing of E-1 facility pressure vessels.

Vessel Number	Vessel Commodity	MAWP (psig)	Volume
V-302-HE	GHE	10,500	15 ft ³
V-375-GH	GH ₂	15,000	625 ft ³
V-376-GH	GH ₂	15,000	625 ft ³
V-377-GH	GH ₂	15,000	625 ft ³
V-381-GN	GN ₂	15,000	625 ft ³
V-382-GN	GN ₂	15,000	625 ft ³
V-397-GN	GN ₂	15,000	625 ft ³
V-398-GN	GN ₂	15,000	625 ft ³
V-399-GN	GN ₂	15,000	625 ft ³
V-099-GN	GN ₂	4,556	1,500 ft ³
V-098-HE	GHE	4,663	1,500 ft ³
V-406-LH	LH ₂	150	5,513 gal
V-133-LH	LH ₂	33	57,500 gal
V-404-LH	LH ₂	385	15,140 gal
V-405-LH	LH ₂	8,500	5,000 gal
V-378-LN	LN ₂	146	28,000 gal
V-403-LO	LOX	9,000	2,600 gal
V-413-LO	LOX	0	28,000 gal
V-379-LO	LOX	146	28,000 gal
V-383-LO	LOX	400	11,240 gal
V-464-RP	RP-1	1,000	7,500 gal
V-471-RP	RP-1	9,000	2,600 gal
V-514-RP	RP-1	9,000	160 gal

Table 3.3 1.4 E-1 Commodity Storage Vessels

3.3.1.4.1 Liquid Oxygen (LOX) (1-6)

A 28,000 gallon LOX vessel provides storage capacity for the 2,600 gallon high pressure LOX run tank and the 11,240 gallon low pressure LOX run tank. A second 28,000 gallon vessel serves as a LOX catch tank with a test article discharge line running to it from the test cells. The following table provides the LOX storage capacities available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (gal)
V-403-LO	HP Run Tank	9,000	2,600
V-383-LO	LP Run Tank	400	11,240
V-379-LO	Storage	146	28,000
V-413-LO	Catch Tank	0	28,000

Table 3.3.1.4.1 E-1 LOX Storage Capacities

3.3.1.4.2 Liquid Hydrogen (LH₂) (18-24)

A 50,000 gallon spherical tank provides liquid hydrogen storage at E-1. Run tank capacities consist of a 5,000 gallon high pressure LH₂ run tank and a 15,140 gallon low pressure LH₂ run tank. In addition, a 5,513 gallon LH₂ tank is used in generating high pressure gaseous hydrogen as discussed in Section 4.3. A high pressure LH₂ flarestack located at E-1 is capable of burning LH₂ at test article discharge flow rates up to 200 lbm/sec at 3,575 psig. The following table provides the LH₂ storage capacities available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (gal)
V-405-LH	HP Run Tank	8,500	5,000
V-404-LH	LP Run Tank	385	15,140
V-133-LH	Storage	33	57,500
V-406-LH	Day Tank	150	5,513

Table 3.3.1.4.2 E-1 LH₂ Storage Capacities

3.3.1.4.3 Gaseous Hydrogen (GH₂)

The E-1 facility has a total of 1,875 ft³ ultra-high pressure (UHP) GH₂ storage capacity. An additional 1,250 ft³ of UHP GH₂ storage capacity is planned. The ultra-

high pressure GH₂ is used to pressurize the HP LH₂ run tanks and to temperature condition LH₂ supplied to test cells 2 & 3. Site wide GH₂ supply is available at E-1 up to 3,000 psig. For higher pressures, LH₂ from the 5,513 gallon day tank is pressurized using an ultra-high pressure pump and then vaporized. A low pressure GH₂ flarestack located at E-1 is capable of burning GH₂ at test article discharge flow rates up to 200 lbm/sec at 600 psig. The following table provides the existing GH₂ storage capacities available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (ft³)	Existing / Future	
V-375-GH	UHP Storage	15,000	625	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-376-GH	UHP Storage	15,000	625	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-377-GH	UHP Storage	15,000	625	<input checked="" type="checkbox"/>	<input type="checkbox"/>
TBD	UHP Storage	15,000	625	<input type="checkbox"/>	<input checked="" type="checkbox"/>
TBD	UHP Storage	15,000	625	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Table 3.3.1.4.3 E-1 GH₂ Storage Capacities

3.3.1.4.4 RP-1

Future plans call for a low pressure and high pressure RP-1 systems at E-1. Also available will be a 20,000 gallon RP-1 storage tank and a 2,000 gallon RP-1 catch tank with a RP-1 discharge line routed to it from the test cells. The following table provides the proposed RP-1 storage capacities to be available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (gal)	Existing / Future	
V-464-RP	LP Run Tank	400	7,000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-471-RP	HP Run Tank	9,000	2,600	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-514-RP	HP Run Tank	9,000	160	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-465-RP	Storage	0.5	20,000	<input checked="" type="checkbox"/>	<input type="checkbox"/>
V-TBD-RP	Catch Tank	50	2,000	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Table 3.3.1.4.4 E-1 RP-1 Storage Capacities

3.3.1.4.5 Liquid Nitrogen (LN₂) (36)

A 28,000 gallon vessel provides liquid nitrogen storage at E-1. The LN₂ is used in generating high pressure gaseous nitrogen as discussed in Section 3.3.1.4.6 and can

also be used in “cold shock” and other activation activities. As necessary, the LOX discharge line and 28,000 gallon LOX catch tank described in section 3.3.1.4.1 can be used in LN₂ service. The table on the next page provides the LN₂ storage capacity available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (gal)
V-378-LN	Storage	146	28,000

Table 3.3 1.4 5 E-1 LN₂ Storage Capacity

3.3.1.4.6 Gaseous Nitrogen (GN₂) (37, 38)

The E-1 facility currently has 3,125 ft³ of ultra-high pressure GN₂ storage capacity and 1,500 ft³ of high pressure GN₂ storage capacity. The ultra-high pressure GN₂ is used to pressurize the high pressure LOX run tank and the high pressure GN₂ is used to pressurize the low pressure LOX run tank. Site wide GN₂ supply is available at E-1 up to 4,500 psig. For higher pressures, LN₂ from the 28,000 gallon storage tank is pressurized using an ultra-high pressure pump and then vaporized. The following table provides the existing and future GN₂ storage capacities available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (ft³)
V-381-GN	UHP Storage	15,000	625
V-382-GN	UHP Storage	15,000	625
V-497-GN	UHP Storage	15,000	625
V-498-GN	UHP Storage	15,000	625
V-509-GN	UHP Storage	15,000	625
V-099-GN	HP Storage	4,556	1,500

Table 3.3.1.4.6 E-1 GN₂ Storage Capacities

3.3.1.4.7 Gaseous Helium (GHe)

The E-1 facility has 1,500 ft³ of high pressure GHe storage capacity and 15 ft³ of ultra high pressure GHe storage capacity. Site wide GHe supply is available at E-1 up to 4,000 psig. In addition, GHe can also be supplied by tube bank trailers. The following table provides the GHe storage capacity available at E-1.

Vessel Number	Description	Max Pressure (psig)	Water Volume (ft³)
V-098-HE	HP Storage	4,500	1,500
V-302-HE	UHP Storage	10,500	15

Table 3.3.1.4.7 E-1 GHe Storage Capacity

3.3.1.4.8 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the E-1 Test Stand.

3.3.1.5 Electrical System Capabilities

The capabilities described below are for each of three test cells.

3.3.1.5.1 Control System

The E1 control system consists of 13 PLCs that are assigned specific tasks in the control and operation of the facility. The PLCs are networked together to allow them to share information and task. I/O and control tasks can be reassigned to meet specific performance goals of a particular test program.

Four facility PLCs provide for the transfer of propellants to storage and run tanks, operation of pumps and vaporizers, and pressurization of run tanks. Generally these subsystems are not actively involved during the actual test. Facility alarms for out-of-tolerance conditions are provided. The facility controls provide a real-time display of operations in a process diagram format.

Other sub-systems provide control over systems that are used for real time control during tests. While many control functions, such as run tank pressurization, are shared by several or all test cells, one PLC is reserved per test cell for test article or test program specific tasks. Redline capability is provided for all of these sub-systems. An additional dedicated redline PLC sub-system is provided for monitoring test specific or test article instrumentation redlines. The system provides the ability to connect up to 80 redline monitoring and shutdown (cutoff) measurements, 16 discrete redlines, and 8 delta redlines per PLC. The redline capability also allows for voting. The PLCs have a nominal loop response (ladder logic scan time) of 21 ms, which does not include analog I/O, instrumentation, or valve delays.

A hardwired emergency abort system is provided to manually override the control system and safely shut down the facility and associated test article systems in a predetermined sequence.

3.3.1.5.2 Instrumentation

Facility instrumentation is installed for real-time display of facility processes and data recording. Instrumentation provided for the test article will be determined with each customer. The facility also provides the ability to display real-time test article measurements. Facility instruments not used during the test, such as those in the storage and transfer areas have a typical response of 250 ms. Instruments that provide test article response information, time critical control functions, or are located at facility to test article interfaces range from 5 to 150 ms response depending on the specific instrument.

There are 320 channels of general-purpose signal conditioning available to excite, amplify, and filter a variety of sensors such as pressure transducers, RTDs and strain gauges, 80 of which can be used for thermocouples. There are also an additional 80 channels of signal conditioning in each cell that are dedicated to thermocouples. The signal conditioning for these channels provides amplification and filtering. In total, up to 160 thermocouple channels are available in each cell. Thermocouples of any type can be accommodated through the use of 6 existing universal temperature reference junctions in each cell. Another 40 channels of signal conditioning are dedicated to each cell providing filtering and amplification. Thus the total signal conditioner count for each cell is 440. An auto calibration capability provides the ability to verify these 440 channels using NIST traceable standards. Other special signal conditioning, such as charge amps, band-pass filters, RMS, and frequency to DC converters are available.

3.3.1.5.3 Low Speed Data Acquisition System

Each test cell (test article & STE) has a dedicated Low Speed Data Acquisition System (LSDAS). There is also one dedicated to the test facility. Each LSDAS can provide up to 512 analog channels and 320 discrete channels with a total throughput of 2MB/s. Tests are typically recorded at 250sps. Log data is recorded 24/7 at 1sps. Each test cell LSDAS has the capability to patch additional channels from an adjacent cell's LSDAS. IRIG B time is recorded on the LSDAS for time correlation between systems. Data is recorded remotely in the TCC. PCGoal is available for transmitting of near real time low speed data to an off site location.

The LSDAS uncertainty is expected to be better than $\pm 0.15\%$, excluding instrumentation and associated cabling. The LSDAS provides a real-time display with an updating rate typically set at 3 times per second. Real-time calculated value capability is available.

3.3.1.5.4 High Speed Data Acquisition System

The High Speed DAS (HSDAS) has three high speed 16 bit digitizers and recorders per test cell. Each digitizer can be configured as follows (1 channel is reserved for IRIG B on each digitizer):

- 63 channels at 50 K SPS (22.5 K Hz)

- 31 channels at 100 K SPS (45.5 K Hz)
- 15 channels at 200 K SPS (80 K Hz)

Typically each digitizer is configured for 32 channels at 100 K SPS per channel. The data is recorded digitally on Super VHS tape along with IRIG B time for correlation. Event channels are also available.

3.3.1.5.5 Data Processing

Data processing is provided for both the LSDAS and the HSDAS. The LSDAS data is converted to Engineering Units and processed into the E-complex standard file format. The LSDAS data file can be provided in Winplot, binary, or an ASCII format. A measurement and calculated values plotting program is available. A quicklook program is also available for preliminary analysis immediately after test. Data backup is provided on DAT or CD-ROM.

The HSDAS data is generally filtered, sub-sampled, and processed to Fast Fourier Transforms (FFT) for frequency analysis. A quicklook dynamic analysis program is available for data reports and quicklook. FFT data format is the same as SSME. Sub-sampled time domain data can be provided in Winplot format. Data backup is provided on CD-ROM for FFT data and SVHS for raw dynamic data.

Off-site data transfer is available for both systems through the Internet.

3.3.1.5.6 Power

AC - The facility power system provides single and three-phase power at 480 VAC, 277 VAC, 208 VAC, 220 VAC and 120 VAC. Uninterruptible Power Supply (UPS) systems provide 220 VAC and 110 VAC power to test critical systems.

DC - Rectifiers provide 28 VDC for control system I/O and are backed up with batteries.

3.3.1.5.7 Video Systems

A low speed video system is available for test article and facility monitoring. Video displays/recorders are provided in the TCC.

A high-speed (HS) video system is used for test article monitoring and recording. Currently three HS video cameras are provided routinely with others provided on an as-available basis. The system is capable of providing up to 500 images per second, available for immediate playback after the test is complete.

IRIG B time is recorded on all systems monitoring the test article for time correlation. Some low speed facility monitoring does not get IRIG stamped.

Additional capabilities include 4 high-speed 35mm cameras, 3 digital video cameras, and 3 digital still cameras.

3.3.1.6 Ancillary Facility Systems

3.3.1.6.1 Deluge Water

The E-Complex shares a 4,000 GPM deluge water system for the purpose of providing deluge cooling water and limiting damage in the event of a fire in a test cell or propellant storage/handling area. Since the system is shared, test activities requiring full deluge capability must be coordinated between facilities. The system covers the following areas: all test cells, all active LOX vessels, all active LH₂ vessels, all active tanker fill headers, and the hydraulics skid. All areas can be remotely operated from the control room. In addition, the deluge nozzles covering the tanker fill headers can be locally operated.

3.3.1.6.2 Plume Impingement Area

A plume impingement area extending southward from Cell 1 is engineered to minimize the effects of heat and acoustic loads generated by a combustion device plume. Water spray nozzles supplied by the deluge water system also cover the plume impingement area.

3.3.1.6.3 Hydraulics

The facility is equipped with a hydraulic system for actuating facility and special test equipment hydraulic valves. The hydraulic system is capable of supplying 180 GPM at 3,000 psig. A smaller jockey pump is capable of supplying 20 GPM at 3,000 psig for low load conditions.

3.3.1.6.4 Communications

The E1 facility is equipped with headset communication boxes in numerous locations to allow voice communication between the Test Control Center and the test facility during operations.

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3.3.2 E-2 Test Facility

The E-2 test facility, formerly known as the High Heat Flux Facility (HHFF), was originally constructed to support materials development testing for the National Aerospace Plane (NASP) by subjecting special test articles to extreme temperature conditions. Recent test projects at E-2 have included composite cryogenic tanks, turbopumps, and preburners. The facility has two test cells capable of accommodating multiple programs at the same time.

Cell 1 is capable of supporting advanced component and engine development projects. Gaseous propellant run, storage and transfer systems are available. A structural blast wall separates the supporting test complex infrastructure from the test cell. A Pebble Bed Heater provides a hot-gas capability. The facility also includes an SCB and an Electrical Equipment Building (EEB). All data acquisition and control aspects are fully functional and are supported by the E-2 TCC, located within the TOB.

Cell 2 is capable of supporting tests of complete flight or "flight-like" stages, as well as rocket engines and combustion devices. Cell 2 has the capability to provide low pressure LOX and RP-1 propellants to a test article, mounted vertically in the test cell. A facility Thrust Measurement System (TMS) is available to measure test article thrust levels. LOX and RP-1 Flow Measurement Systems (FMS), utilizing turbine flow meters, are available to measure LOX and RP-1 flow rates from facility run tanks.



E-2 Cell 1

3.3.2.1 E-2 Cell 1 [26]

Cell 1 has the capability to provide a maximum 100,000 lbf thrust combustion device or turbopump with LOX, LN_2 , LH_2 , RP-1, H_2O , GH_2 , O_2 , GOX, and GN_2 . LOX tanks can be used for LN_2 service. The facility is equipped with an ablative coated concrete pad located east of the test cell and is capable of withstanding the pressure and heat loads generated by a combustion device or turbopump weighting no more than 3,000 lbs.

The test stand is capable of mounting a combustion device or turbopump at various downward angles from the horizontal and is capable of taking side loads of up to 15,000 lbs.

3.3.2.1.1 Commodity Storage and Capabilities

LOX, LN₂, LH₂, RP-1, H₂O, GH₂, ₂, GOX, and GN₂ can be supplied to test articles in E-2 in accordance with the facility pressure vessels as shown in the following table.

Vessel Number	Vessel Commodity	MAWP (psig)	Volume
Propellant Run Systems			
V-389-RP	RP-1	9,000	500 gal.
V-385-RP	RP-1	6,000	145 gal.
V-386-RP	RP-1	1,800	846 gal.
V-455-CW/RP	H ₂ O/RP-1	4,000	2,000 gal.
V-065-GO	GO ₂	4,500	1,375 ft ³
V-390-LO	LO ₂	9,300	500 gal.
V-380-LO	LO ₂	185	10,000 gal.
V-384-CW	RP-1/H ₂ O	6,000	145 gal.
V-473-LH	LH ₂	400	15,000 gal.
X-PBH-GH	Hot GH ₂	6,600 (400 F)	65 ft ^{3*}
Pressurization Systems			
V-387-GN	GN ₂	15,000	247 ft ³
V-145-GN	GN ₂	5,667	1,500 ft ³
V-142-GN	GN ₂	5,667	1,375 ft ³
V-388-GH	GN ₂ /GH ₂	15,000	625 ft ³
V-264-GH	GH ₂	6,600	750 ft ³
V-265-GH	GH ₂	6,600	750 ft ³
Propellant Storage/Dump Systems			
V-268-LO	LO ₂	150	3,000 gal.

* Vessel volume minus refractory brick and pebbles (gas volume) is 27.5 ft³

Table 3.3.2.1.1-1 E-2 Cell 1 Facility Pressure Vessels

System	Max. Tank Opr. Press (psig)	Max. Flow Rate @ Max Oper Pressure (lbm/sec)	Duration for Max. Press/flow rate Case (sec)	Available Commodity with Standard Margins (1)
UHP LO ₂	8,000	400	3	400 gal.
LP LO ₂	165	275	277	8,000 gal.
(4) GO ₂	4,100	65	100	n/a
LO ₂ Discharge	n/a	275	70	n/a
UHP RP-1	8,000	350	5	400 gal.
HP RP-1 (coolant)	5,500	60	12	116 gal.
MP RP-1	1,600	140	30	677 gal.
HP RP-1	3,800	300	35	1,600 gal.
LP LH ₂	360	55	112	10,500 gal
(2)GH ₂	6,000	19	35	n/a
♦ (5) Hot GH ₂	6,000	10	40	n/a
12" LH ₂ Flare-stack	n/a	15	n/a	n/a
42" GH ₂ Flare-stack	n/a	81	n/a	n/a
HP CW	5,500	75	12	116 gal.
(6) HP CW	3,800	380	35	1,600 gal
(3) GN ₂	6,000	70	95	n/a
TEA/TEB	5,500	1.0	6	1.5 gal.

Table 3.3.2.1.1-2 E2 Cell 1 Propellant/Coolant/Turbine Drive/Discharge Systems Capabilities

Table 3.3.2.1.1-2 Notes:

- (1) "Amount of commodity available using standard margins" column as specified includes standard margins (ullage, residual, boil-off, and bleed): 20% for RP-1, H₂O; 30% for LOX, LN₂, LH₂.
 - (2) Case with GH₂ bottles (V-264-GH and V-265-GH) used in GH₂ service for either turbine drive or combustion device application, blowing down from 6,000 psig to 3,500 psig. Maximum flowrate provided duration illustration only.
 - (3) Case with GH₂ bottles (V-264-GH and V-265-GH) used in GN₂ service for turbine drive application, blowing bottle down from 6,000 psig to 3,500 psig.
 - (4) Case with GOX bottle (V-065-GO) used in combustion device application, blowing down from 4,100 psig to 3,500 psig. maximum flowrate based on maximum safe GOX velocity of 125 ft/sec.
 - (5) The hot hydrogen system temperature capability in terms of test duration at a specific temperature will be determined during activation. The design target is 100 seconds at 4.0 lbm/sec @ 2500 PSIA @ 750 °F ± 100 °F.
 - (6) Case with V-455 in H₂O service.
- ♦ Future capability

3.3.2.1.1.1 Liquid Oxygen (LOX)

If needed by a testing customer, a 6,000 psi/6 GPM LOX pump can be made operational. It can be used for the purpose of pressurizing the GOX vessel to 4,500 psi via a 6,000 psi vaporizer. This pump is supplied by LOX vessel V-268-LO. The GOX vessel can be charged from 0 psig to 4,500 psig in 15 hours.

3.3.2.1.1.2 Liquid Hydrogen (LH₂)

Cell 1 has a flarestack capable of burning test article LH₂ discharges as specified in Table 3.3.2.1.1-2.

3.3.2.1.1.3 Gaseous Hydrogen (GH₂)

The Cell 1 Ultra High Pressure vessels for GH₂/GN₂ (625 ft³) are rechargeable from the site-wide average 3,000 psig to 15,000 psig in 12 hours. This is accomplished using the E-1 facility UHP system and a cross-country line between E-1 and E-2. GH₂ vessels can also be pressurized from 3,000 psig to 6,600 psi using the E-1 GH₂ cross-country line in approximately 8 hours.

Cell 1 is equipped with a flarestack capable of burning test article GH₂ discharges as specified in Table 3.3.2.1.1-2.

3.3.2.1.1.4 RP-1

Cell 1 has an RP-1 discharge line routed to a waste tank at the north side of the test cell blast wall. This system has the capabilities specified in Table 3.3.2.1.1-2.

3.3.2.1.1.5 Liquid Nitrogen (LN₂)

LN₂ is not currently available at E2 Cell 1.

3.3.2.1.1.6 Gaseous Nitrogen (GN₂)

The E-2 Ultra High Pressure vessels for GH₂/GN₂ (625 ft³) and GN₂ (247 ft³) are rechargeable from the site-wide average 3,000 psig to 15,000 psig in 12 hours. This is accomplished using the E-1 facility UHP system and a cross-country line between E-1 and E-2.

If needed by a testing customer, a 6,000 psi/6 GPM LOX pump, supplied by LOX vessel V-268-LO, can be made operational in LN₂ service to charge the GN₂ vessels from site-wide average 3,000 psig to 5,667 psig in 9 hours or vessel V-10A09-GN to 6,000 psig in approximately 3 hours.

3.3.2.1.1.7 Gaseous Helium (GHe)

Site wide GHe supply is available at E-2 up to 4,400 psig.

3.3.2.1.1.8 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the E-2 Test Stand.

3.3.2.1.2 Electrical System Capabilities

The following sections will briefly describe the control system, instrumentation, Low Speed and High Speed DAS systems, data processing, power and video systems.

3.3.2.1.2.1 Control System

The E2 Cell 1 and Cell 2 TCC are co-located in the E-Complex TOB. It serves as the central command for the test conductor and test personnel during test operations. The real-time process control information is monitored on TCC computer screens running WonderWare Operator Interface (OI) software.

The facility control system PLC1 handles the transfer of propellants to storage and run tanks, operation of pumps, vaporizers, and hydraulics. It is also used for run tank pressurization, pressure ramping, and facility valve control. Facility blueline and redline monitoring for out of tolerance conditions is provided.

The STE control system PLC2 handles STE and test article propellant flows, purges, coolant, and ignition; configured for each test article. It contains a general automatic sequencer that can be configured for a test article specific test sequence. The system provides blueline and redline monitoring and shutdown (cutoff).

The control system can provide the following number of control channels for STE and a test article:

- 93 patched transducers
- 77 analog inputs for transmitters
- 101 discrete valves
- 32 variable position control valves (16 for hydraulic actuation; 16 for pneumatic actuation)
- 194 discrete inputs
- 128 (patched) plus 512 analog blueline/redline channels including facility
- 1024 discrete blueline/redline channels including facility

A hardwired Emergency Shutdown System is provided that manually overrides the control systems and shuts down the facility and associated test article systems in a predetermined four-stage timed sequence.

3.3.2.1.2.2 Instrumentation

Facility instrumentation is installed for real-time display and data recording, and control of facility processes. Instrumentation provided for the test article will be determined with each customer. The facility also provides the ability to display real-time test article measurements. Each measurement is sampled and stored at 250 samples/second. Instruments that provide test article response information, time critical control functions, or are located at facility to test article interfaces have a typical 5 to 250 ms response depending on the specific instrument.

3.3.2.1.2.3 Low Speed Data Acquisition System

The LSDAS provides general-purpose signal conditioning available to excite, amplify, and filter a variety of sensors, such as pressure transducers, RTDs, strain gages, and thermocouples. Thermocouples of any type can be accommodated through the use of universal temperature reference junctions in the test cell. The total throughput of all measurements is 250 SPS of 16 bit per measurement data. Test article and all control system analog and discrete inputs and outputs data are recorded on the LSDAS in the TCC. IRIG B is recorded on the LSDAS for time correlation between systems.

The LSDAS provides the following number of monitoring channels:

- 220 programmable bridge-completion amplifiers
- 70 filter amplifiers
- 26 raw input channels
- 458 control system analog inputs
- 64 control system analog outputs
- 608 control system discrete inputs
- 416 control system discrete outputs

The LSDAS end-to-end uncertainty is $\pm 0.15\%$, excluding instrument and associated cabling. An automated calibration capability provides the ability to verify the signal conditioning amplifiers using NIST traceable standards.

The LSDAS provides a real-time tabular or graphical display of data system measurements. These displays can be transmitted to off-site customer locations and to redundant data recording. Real-time calculated values are available. The LSDAS also provides an interface to the PCGoal system for transmission of near real time low speed data to an off-site location.

3.3.2.1.2.4 High Speed Data Acquisition System

The HSDAS has two high speed 16 bit digitizers and recorders. Each digitizer can be configured as follows (1 channel is reserved for IRIG B on each digitizer):

- 63 channels at 50 KSPS (22.5 KHz)
- 31 channels at 100 KSPS (45.5 KHz)
- 15 channels at 200 KSPS (80 KHz)

Typically each digitizer is configured for 32 channels at 100 KSPS per channel. The data is recorded digitally on Super VHS tape along with IRIG B time for correlation. Event channels are also available.

3.3.2.1.2.5 Data Processing

Data processing is provided for both the LSDAS and HSDAS. The LSDAS data is converted to Engineering Units, time aligned (to T=0) and processed into the Winplot file format. The LSDAS data file also can be provided in ASCII format. A measurement and calculated values plotting program is available. A quicklook program is also available for on-line analysis. Data backup is provided on CD ROM.

The HSDAS data is generally filtered, sub-sampled, and processed to Fast Fourier Transforms (FFT) for frequency analysis. A quicklook dynamic analysis program is available for data reports and quicklook. FFT data format is the same as SSME. Sub-sampled time domain data can be provided in Winplot format. Data backup is provided on CD-ROM for FFT data and SVHS for raw dynamic data.

Post test, off-site data transfer is available for both data systems through the Internet. Data security is provided through password protection. Data encryption is also available.

3.3.2.1.2.6 Power

AC - The facility power system provides single and three-phase power at 480VAC, 277VAC, 208VAC, 240VAC, and 120VAC. Uninterruptible power supply (UPS) systems provide a minimum of ten minutes of 120VAC power to test critical systems. 240/120 VAC is available for test article use.

DC - 28V and 24V DC is provided for control system I/O. The DC power supplies are sourced from the control system UPS. 28 VDC is also available for test article use.

3.3.2.1.2.7 Video Systems

Six low speed video cameras (30 frames/second) are available for test article and facility monitoring, one of which is portable. IR filters can be installed on the existing low-speed cameras if required. Video displays and recorders (operating at 30

frames/second), switchers and pan/tilt/zoom controls are provided in the Test Control Center.

A high-speed video system enables viewing and recording of the test article using three high-speed cameras with pan/tilt/zoom capability, two of which are portable. The high-speed video is capable of up to 500 frames/sec with reduced screen resolution, or full screen resolution is available at 250 frames/sec. Video tape recorders for high-speed video recording are located in the SCB near the test stand. Three 35 mm cameras and one digital portable camera can also be used for the test article and facility.

IRIG B is recorded on all video systems for time correlation.

3.3.2.1.3 Ancillary Facility Systems

The following sections describe the test article support stand, hydraulics system, plume impingement area and deflector, deluge system and communications.

3.3.2.1.3.1 Test Article Support Stand

The E-2 Cell 1 test article support stand is designed to support a test article weighing up to 3,000 lbs and generating up to 100,000 lbs of thrust (with a dynamic load factor of 2). The orientation of the support stand has the test article plume directed eastward from the test cell. The support stand is designed such that the test article centerline can be mounted from 60 to 120 inches off the test cell floor (the test cell floor is 30 inches below the grating). The test stand is capable of mounting a combustion device at various downward angles from the horizontal and is capable of taking side loads of up to 15,000 lbs.

3.3.2.1.3.2 Hydraulics System

The facility includes a hydraulic system for actuating facility, STE, or test article hydraulic valves. The system at Cell 1 is capable of generating 3,000 psig and 46 GPM with a 200 gallon hydraulic fluid reservoir, with redundant 100 HP pumps. The hydraulic fluid is cooled with a fan-cooled oil-air heat exchanger.

3.3.2.1.3.3 TEA/TEB Ignition System

Facilities are available for filling, storing, and transporting Triethyl-Aluminum (TEA) and Triethyl-Borane (TEB) test article ignition canisters.

3.3.2.1.3.4 Plume Impingement Area

The facility plume impingement area can be coated with an ablative capable of withstanding the pressure and heat loads generated by a 100,000 lbs thrust class combustion device. Water spray nozzles supplied with water from the deluge water

system can be added to reduce the temperature of the impingement area depending on the duration of the test firing. The location and size of the concrete pad can accommodate combustion devices mounted at the top of the test article support stand (120 inches from the floor of the cell) and canted downward at up to a 10 degree angle from the horizontal.

3.3.2.1.3.5 Deluge System

The facility has a 4,000 GPM 225 psi MAWP water deluge system for the purpose of limiting damage in the event of a test stand fire. The Cell 1 Deluge System covers the following areas: Test cell, all active LOX vessels, all active LH₂ vessels, all active RP-1 vessels, all active GOX vessels, the Pebble Bed Heater, and all active trailer fill headers. All deluge areas can be manually initiated locally, or remotely from the TCC via hardwired relays and switches on the Test Conductor console. The deluge nozzles covering the trailer fill headers and storage tanks are fail-dry whereas all other areas are selectable fail-wet or fail-dry.

3.3.2.1.3.6 Communications

The facility communications system has the capability to provide communications between the Test Control Center and the test cell.

3.3.2.1.5.7 DI Water Supply System

The facility can be equipped with a Deionized Water system that can convert potable water to deionized water with conductivity as low as 15 Mohms resistance at a rate up to 24 GPM. This system can be used to supply coolant to high frequency dynamic pressure transducers or to fill the Coolant Water run system tanks.

3.3.2.1.5.8 Fire and Gas Detect System

The E2 Test Complex employs a fire and gas detection system with a display within the E2 TCC that is independent of the Facility and Test Article Control System. The gas detect system provides operators within the TCC visibility into the location of gaseous hydrogen leaks around the GH bottles.

Fire detection for active hydrogen piping can be provided via a zoned resistive-wire detection system. The 2-conductor insulation melts with heat, shorting the wires and initiating a zone alarm. The resistive wires are routed around flanges and valve stems at potential fire locations. Zones are selected to provide fire indication in a limited area.

3.3.2.1.5.9 Pebble Bed Heater

A hot hydrogen capability is provided by a Pebble Bed Heater with capability as shown in Table 3.3.2.1.1-1. This system has been installed and partially activated, awaiting a customer need.

3.3.2.2 E-2 Cell 2 [27]

Currently, the E-2 Cell 2 Test Facility is capable of testing complete flight stages or "flight-like" test article stages up to 324,000 lbf thrust in a vertical orientation. LOX and RP-1 propellant supply systems are presently available at this stand along with high pressure He and GN₂ gas supply systems.



E 2 Cell 2

The vertical test cell, which runs from the rolling deck platform to the top of the test cell structure, measures 22 ft 4 in x 22 ft 4 in x 58 ft 10 in. The diamond-shaped thrust takeout structure reaction beams provide a 15 ft x 15 ft area to accommodate test articles. Larger test articles, up to about 22 ft in diameter, can be accommodated by making structural modifications to the test cell. Access stairs are provided at both the north and south sides of the test stand.

A facility TMS is available for thrust ranges from 10,000 lbs to 100,000 lbs. RP-1 and LOX facility run tanks, an H₂O₂ drain system, and DI water systems are available. More detailed descriptions of these systems are provided in the sections that follow.

3.3.2.2.1 Commodity Storage and Capabilities

Facility pressure vessels are listed in Table 3.3.2.2.1-1, along with their Maximum Allowable Working Pressures (MAWP), volumes, and cleanliness levels. The facility currently provides 2 inch LOX and RP-1 transfer lines from the facility storage tanks to the test cell for test article use. Table 2 summarizes the planned capabilities of the future LOX and RP-1 run systems, including operating pressures, maximum flow rates, and run durations. The values provided in Table 3.3.2.2.1-2 are nominal predicted values. Actual values will be determined during facility activation prior to test.

Vessel Number	Vessel Commodity	MAWP (psig)	Volume (gal)
Propellant Run Tanks¹			
V-103-LO	LOX	120	5,500
V-196-RP	RP-1	125	5,500
Propellant Storage Systems			
V-14A1210-RP	RP-1	14	15,000

1.) Run tanks are installed but not currently plumbed to test cell

Table 3.3.2.2.1-1 E2 Cell 2 Facility Pressure Vessels

System	Max. Tank Press. (psig)	Max. STE Interface Pressure ¹ (psig)	Max. Flow Rate (lbm/sec)	Duration (at max. press. & flow rate) (sec)	Available Propellant (std. margins) ² (gal)	Existing/ Future
LOX Run	120	70	330	122	3,850	<input type="checkbox"/> <input checked="" type="checkbox"/>
RP-1 Run	125	64	150	212	4,400	<input type="checkbox"/> <input checked="" type="checkbox"/>

Table 3.3.2.2.1-2 E2 Cell 2 Future Run System Capabilities

Table 3.3.2.2.1-2 Notes:

- 1.) Calculated estimate for maximum propellant flow rates
- 2.) Includes standard reductions in available propellant volume for ullage (10%), residual/heel (10%), and, for LOX, boil-off/bleed (10%), which gives a total volume reduction of 20% for RP-1 and 30% for LOX
- 3.) For maximum propellant flow conditions
- 4.) Pressurization system ramp rate is a static ramp rate of the run tank ullage with no flow out of the tank. These are nominal predicted values. These ramp rates do not include valve actuation times, which could be a significant factor on the high-pressure vessel pressurization rates. All cases assume 10% ullage volume and pressurization from 0 to MAWP of vessel.
- 5.) "Amount of commodity available using standard margins" column as specified includes standard margins (ullage, residual, boil-off, and bleed): 20% for RP-1, H₂O, 30% for LOX, LN₂, and LH₂.

3.3.2.2.1.1 Liquid Oxygen (LOX)

The facility provides a 2 in. transfer line from the facility storage tank to the test cell for test article use.

The facility includes a 4 in. LOX dump/bleed line to facilitate chill down and draining of the test article. The line is routed from the test cell to the E-2 Cell 2 LOX dump system, which terminates in a LOX dump pond located at the northeast corner of the E-2 Cell 2 test area.

3.3.2.2.1.2 Liquid Hydrogen (LH₂)

LH₂ is not currently available at E-2 Cell 2.

3.3.2.2.1.3 Gaseous Hydrogen (GH₂)

GH₂ is not currently available at E-2 Cell 2.

3.3.2.2.1.4 RP-1

The facility provides a 2 in. transfer line from the facility storage tank to the test cell for test article use.

A 4 in. RP-1 dump/bleed line is provided to facilitate test article draining. The line is routed from the test cell to the Cell 2 RP-1 storage tank on the southwest corner of the Cell 2 test area.

3.3.2.2.1.5 Liquid Nitrogen (LN₂)

LN₂ is not currently available at E-2 Cell 2.

3.3.2.2.1.6 H₂O₂ Drain System

A 6 in. diameter drain line is in place to dispose of up to 98% concentration H₂O₂ at a rate of 32 GPM. The drain system consists of the drain line and a potable water flush system that dilutes the hydrogen peroxide to a maximum 8% concentration before discharging it into a containment pond. Greater discharge flowrates are allowed in emergency situations, in which case the dilution requirement is not applicable.

3.3.2.2.1.7 Gaseous Nitrogen (GN₂)

E-2 Cell 2 uses the site-wide GN₂ system as a source for propellant run tank pressurization and for facility system and test article purges. GN₂ is supplied to the test stand by 1-1/2 in. diameter supply lines. The 4,100 psig (maximum) site-wide pressure is regulated down to meet lower pressure facility and test article operational requirements. GN₂ is available at LOX compatible cleanliness levels (SSC Level 1XX).

3.3.2.2.1.8 Gaseous Helium (GHe)

Site-wide helium (at 4,400 psig, maximum) is also available for pressurization and purging. GHe is supplied to the test stand by 1-1/2 in. diameter supply lines. GHe is available at LOX compatible cleanliness levels (SSC Level 1XX).

3.3.2.2.1.9 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the E-2 Test Stand.

3.3.2.2.2 Electrical System Capabilities

The following sections will briefly describe the control system, instrumentation, Low Speed and High Speed DAS systems, data processing, power and video systems.

3.3.2.2.2.1 Control System

The E2 Cell 2 and Cell 1 Test Control Center (TCC) are co-located in the E-Complex Test Operations Building (TOB). It serves as the central command for the test conductor and test personnel during test operations. The real-time process control information is monitored on TCC computer screens running WonderWare Operator Interface (OI) software.

The facility control system PLC1 handles the transfer of propellants to storage and run tanks, operation of pumps, vaporizers, and hydraulics. It is also used for run tank pressurization, pressure ramping, and facility valve control. Facility blueline and redline monitoring for out of tolerance conditions are provided.

The STE control system PLC2 handles STE and test article propellant flows, purges, coolant, and ignition; configured for each test article. It contains a general automatic sequencer that can be configured for a test article specific test sequence. The system provides blueline and redline monitoring and shutdown (cutoff).

The control system can provide the following number of control channels for STE and a test article:

- 48 patched transducers
- 96 analog inputs for transmitters
- 40 discrete valves
- 16 variable position control valves (8 for hydraulic actuation; 8 for pneumatic actuation)
- 122 discrete inputs
- 48 (patched) plus 208 analog blueline/redline channels including facility
- 512 discrete blueline/redline channels including facility

A hardwired Emergency Shutdown System is provided that manually overrides the control systems and shuts down the facility and associated test article systems in a predetermined four-stage timed sequence.

3.3.2.2.2 Instrumentation

Facility instrumentation is installed for real-time display and data recording, and control of facility processes. Instrumentation provided for the test article will be determined with each customer. The facility also provides the ability to display real-time test article measurements. Each measurement is sampled and stored at 250 samples/second. Instruments that provide test article response information, time critical control functions, or are located at facility to test article interfaces have a typical 5 to 250 ms response depending on the specific instrument.

3.3.2.2.3 Low Speed Data Acquisition System

The Low Speed Data Acquisition System (LSDAS) provides general-purpose signal conditioning available to excite, amplify, and filter a variety of sensors, such as pressure transducers, RTDs, strain gages, and thermocouples. Thermocouples of any type can be accommodated through the use of universal temperature reference junctions in the test cell. The total throughput of all measurements is 250 SPS of 16 bit per measurement data. Test article and all control system analog and discrete inputs and outputs data are recorded on the LSDAS in the TCC. IRIG B is recorded on the LSDAS for time correlation between systems.

The LSDAS provides the following number of monitoring channels:

- 160 programmable bridge-completion amplifiers
- 60 filter amplifiers
- 36 raw input channels
- 176 control system analog inputs
- 16 control system analog outputs
- 370 control system discrete inputs
- 192 control system discrete outputs

The LSDAS end-to-end uncertainty is $\pm 0.15\%$, excluding instrument and associated cabling. An automated calibration capability provides the ability to verify the signal conditioning amplifiers using NIST traceable standards.

The LSDAS provides a real-time tabular or graphical display of data system measurements. These displays can be transmitted to off-site customer locations and to redundant data recording. Real-time calculated values are available. The LSDAS also provides an interface to the PCGoal system for transmission of near real time low speed data to an off-site location.

3.3.2.2.2.4 High Speed Data Acquisition System

The High Speed DAS (HSDAS) has three high speed 16 bit digitizers and recorders. Each digitizer can be configured as follows (1 channel is reserved for IRIG B on each digitizer):

- 95 channels at 50 KSPS (22.5 KHz)
- 47 channels at 100 KSPS (45.5 KHz)
- 23 channels at 200 KSPS (80 KHz)

Typically each digitizer is configured for 32 channels at 100 KSPS per channel. The data is recorded digitally on Super VHS tape along with IRIG B time for correlation. Event channels are also available.

3.3.2.2.2.5 Data Processing

Data processing is provided for both the LSDAS and HSDAS. The LSDAS data is converted to Engineering Units, time aligned (to T=0) and processed into the Winplot file format. The LSDAS data file also can be provided in ASCII format. A measurement and calculated values plotting program is available. A quicklook program is also available for on-line analysis. Data backup is provided on CD ROM.

The HSDAS data is generally filtered, sub-sampled, and processed to Fast Fourier Transforms (FFT) for frequency analysis. A quicklook dynamic analysis program is available for data reports and quicklook. FFT data format is the same as SSME. Sub-sampled time domain data can be provided in Winplot format. Data backup is provided on CD-ROM for FFT data and SVHS for raw dynamic data.

Post test, off-site data transfer is available for both data systems through the Internet. Data security is provided through password protection. Data encryption is also available.

3.3.2.2.2.6 Power

AC - The facility power system provides single and three-phase power at 480VAC, 277VAC, 240VAC, and 120VAC. Uninterruptible power supply (UPS) systems provide a minimum of ten minutes of 120VAC power to test critical systems. 240/120 VAC is available for test article use.

DC - 28V and 24V DC is provided for control system I/O. The DC power supplies are sourced from the control system UPS. 28 VDC is also available for test article use.

3.3.2.2.2.7 Video Systems

Six low speed video cameras (30 frames/second) are available for test article and facility monitoring, one of which is portable. IR filters can be installed on the existing low-speed cameras if required. Video displays and recorders (operating at 30

frames/second), switchers and pan/tilt/zoom controls are provided in the Test Control Center.

A high-speed video system enables viewing and recording of the test article using three high-speed cameras with pan/tilt/zoom capability, two of which are portable. The high-speed video is capable of up to 500 frames/sec with reduced screen resolution, or full screen resolution is available at 250 frames/sec. Video tape recorders for high-speed video recording are located in the SCB near the test stand.

IRIG B is recorded on all video systems for time correlation.

Three 35 mm cameras and one digital portable camera can also be used for the test article and facility.

3.3.2.2.3 Additional Facility Capabilities

Additional E-2 Cell 2 facility capabilities are described in the sections that follow.

3.3.2.2.3.1 Test Article Support Structure

The E-2 Cell 2 facility is capable of supporting test articles, including complete flight or flight-like stages, generating up to 324,000 lbf thrust (with a dynamic load factor of 2) in a vertical orientation. The thrust bearing capability of the facility is currently limited by the load bearing capacity of the flame deflector. The facility is capable of supporting active test article gimbaling during hot fire and is capable of taking side loads of up to 12,000 lbf.

A rolling deck (rated to 8,000 lbm) and crane system (rated to 6,000 lbm) are available to facilitate test article positioning and installation.

3.3.2.2.3.2 Flame Deflector

The facility is equipped with an ablative flame deflector to direct engine plume gases away from the test article and test stand (i.e., toward the east side of the test stand). It is capable of withstanding the pressure and heat loads generated by a 120,000 lbf thrust class engine or combustion device. The deflector is capable of supporting active gimbaling during hot fire. Gimbaling limits will be identified as required based on specific test article thrust levels and plume phenomenology.

3.3.2.2.3.3 Deluge System

The facility has a 4,000 GPM, 225 psig MAWP water deluge system for the purpose of limiting damage in the event of a test stand fire. The deluge system covers all four test cell levels, along with the test stand structure, LOX run tank, RP-1 run tank, LOX and RP-1 storage tanks, and the LOX and RP-1 tanker fill headers.

All deluge areas can be manually initiated locally, or remotely from the TCC via hardwired relays and switches on the Test Conductor console. The deluge nozzles covering the trailer fill headers, storage tanks, and test stand structure are fail-dry whereas all other areas are selectable fail-wet or fail-dry.

3.3.2.2.3.4 GN₂ Heated Purge System

A GN₂ heated purge system is available to facilitate engine drying and RP-1 evaporation. The system is capable of providing 170 °F (maximum) GN₂ at 150 psig (nominal) with flow rates of 100 SCFM.

3.3.2.2.3.5 Mobile Engine Service Panel

A mobile engine service panel is available to facilitate leak checks on test articles by enabling remote pressurization of the test article using GN₂ or GHe. GN₂ at 100 psig and 800 psig and GHe at 100 psig are available at LOX cleanliness levels (SSC level 1XX). GN₂ and GHe at 100 psig are available at RP-1 cleanliness levels (SSC level 2X). Pressure measurement ports for reading internal engine pressures during pressurization and leak check are included on the panel.

3.3.2.2.3.6 Communications System

The facility communications system has the capability to provide voice communications throughout the E-2 Test Facility.

3.3.2.2.3.7 DI Water Supply System

The facility can be equipped with a De-ionized Water system that can convert potable water to de-ionized water with conductivity as low as 15 Mohms resistance at a rate up to 24 GPM. This system can be used to flush/rinse H₂O₂ systems; to supply coolant to high frequency dynamic pressure transducers or to fill the Coolant Water run system tanks. This system can be connected to rinse stations located on the test stand.

3.3.2.2.3.8 Test Article Access

The E2 Cell 2 test stand has removable sections on the east side of the structure for more convenient and cost-effective placement and removal of test articles into the test stand.

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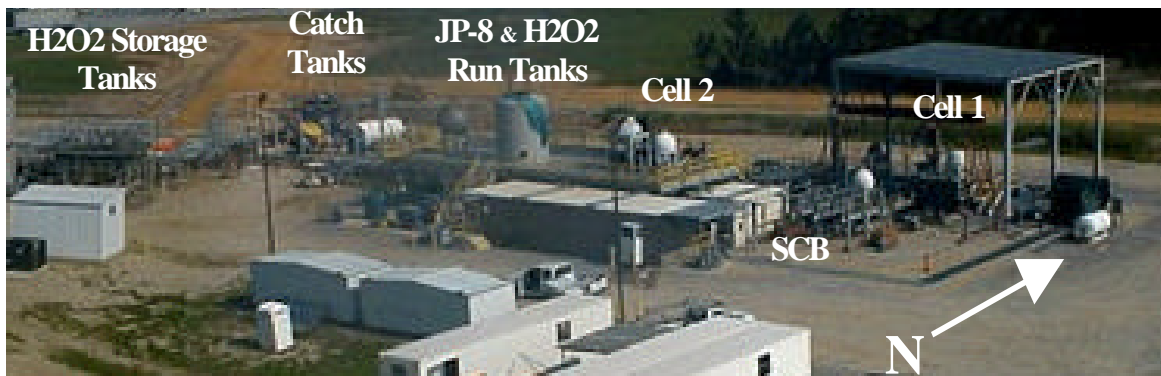
3.3.3 E-3 Test Facility [28]

The E-3 Test Facility is a versatile test complex available for component development testing of combustion devices, rocket engine components and small/sub-scale complete engines and boosters. The facility currently has two test cells. Cell 1 is a horizontal test stand, which can support horizontal thrust loads up to 60,000 lbf (120,000 lbf impulse load). Cell 2 is primarily utilized for vertical testing with provisions for limited horizontal testing. Cell 2 can support vertical thrust loads up to 25,000 lbf thrust (50,000 lbf impulse load). Cell 2 has a flame bucket below the firing position. The addition of a third test cell (Cell 3) is under consideration.

The facility has the capacity to deliver propellants at low and medium pressures, up to 3,000 psi. All propellant storage, transfer, and run systems for LOX and GOX are cleaned to cleanliness level 1XX per SSTD-8070-0089-FLUIDS. H_2O_2 systems are also passivated. The methane system is cleaned to a level 2X. The JP systems are cleaned to a level 2X and are maintained at Level 3. From the final filter to the test article interface, the run systems are maintained to Level 2X. GH_2 is available from the site-wide system and can be delivered with cleanliness Level 2X.

Single-axis thrust measurement capability is available for both Cell 1 and Cell 2. Currently, 10,000 lbf and 25,000 lbf TMS are available for use. An additional TMS unit of 60,000 lbf capacity is available at Cell 2.

Test Cells 1 and 2 can be occupied at the same time, providing a multiple program capability. Both test cells are adequately illuminated for night time work.



E-3

3.3.3.1 E-3 Cell 1



E 3 Cell 1

Cell 1 was primarily designed to test pressure-fed LOX/hydrocarbon fuel, GOX/hydrocarbon fuel, GH_2/GOX , and hybrid rocket motor combustion devices. JP and H_2O_2 run systems have also been installed in Cell 1. Cell 1 has two thrust positions. Both positions are capable of supporting horizontal thrust loads of up to 60,000 lbf (120,000 lbf impulse load). The actual thrust capability will depend on the test article mounting position and thrust centerline orientation and can be evaluated on a case-by-case basis. Additionally, Cell 1 has a small component test position developed for hybrid rocket testing that is capable of supporting 3,000 lbf thrust loads (6,000 lbf impulse load). Cell 1 is 38 ft. in width by 40 ft. in length and is covered with a roof 25 ft. in height. A 5-ton overhead crane provides lifting capability up to a height of 18 ft. The run tanks are conveniently located to suit the test programs. The Table 3.3.3.1 on the next page outlines the existing and planned upgrade commodity supply capabilities for Cell 1. The flow rates listed in the table are nominal. A 4 in. LOX/ LN_2 discharge (drain) line is routed east of the cell to a ditch located north of the facility.

Commodity	Pressure (psig)	Volume (gal)	Temperature (°R / °F)	Flow Rate (lbm/sec)	Supply/ Run Line (in.)	Existing / Upgrade	
LOX	1,500 ¹	100	163 / -297	9 ³	1	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LOX	1,500 ¹	100	163 / -297	22	1 ½	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LN ₂	1,500 ¹	100	144 / -316	8 ³	1	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LN ₂	1,500 ¹	100	144 / -316	16	1 ½	<input checked="" type="checkbox"/>	<input type="checkbox"/>
H ₂ O ₂ /LOX	3,000	500	540 / 80 163/ -297	220/112 ⁴	4	<input checked="" type="checkbox"/>	<input type="checkbox"/>
JP-8	3,000	250	540 / 80	40	2	<input checked="" type="checkbox"/>	<input type="checkbox"/>
H ₂ O ₂ /LOX	3,000	500	540 / 80 163/ -297	30/15 ⁴	1 ½	<input type="checkbox"/>	<input checked="" type="checkbox"/>

1 - Limited by run line components

2 - K-bottle maximum limit

3 - Maximum flow rate for flow-meter

4 – Maximum flow rate limited by velocity (25 ft/sec)

Table 3.3.3.1 Cell 1 Commodity Supply Capabilities

3.3.3.2 E-3 Cell 2



E 3 Cell 2

Cell 2 was primarily designed to test H₂O₂/JP-8 and rocket motor combustion devices up to 25,000 lbf of vertical thrust (50,000 lbf impulse load). Cell 2 has an additional capacity to test mono-propellant configuration sub-scale combustion devices, such as, catalyst beds and components. Table 3.3.3.2 outlines the commodity supply capabilities for Cell 2, with flow rates being nominal.

Cell 2 features a skid based design concept. In this concept, the test article is mounted on a platform that is bolted above the 8 ft wide by 17 ft deep concrete flame bucket with a 48 inch by 48 inch access hole provided for vertical testing. A 500 gallon oxidizer run tank and a 250 gallon fuel run tank are located next to each other on an elevated platform 8 ft above and to the south of the test cell platform. Cell 2 also has a dedicated flare stack.

Two vertical thrust takeout structures are available, mounted above the flame bucket access hole. One can be outfitted with existing 10,000 lbf thrust single axis TMS, whereas the other is shorter and stiffer, but does not have TMS capability. The maximum vertical thrust rating is limited to 25,000 lbf. Mobile cranes are available to provide lifting capability.

Commodity	Pressure¹ (psig)	Volume (gal)	Temperature (°R / °F)	Flow Rate² (lbm/sec)	Run Line (in.)	Existing / Upgrade	
H ₂ O ₂ /LOX	3,000	500	540 / 80 163 / -297	220 / 112 ¹	4	<input checked="" type="checkbox"/>	<input type="checkbox"/>
JP-8	3,000	250	540 / 80	40	2	<input checked="" type="checkbox"/>	<input type="checkbox"/>
H ₂ O ₂ /LOX	3,000	500	540 / 80 163 / -297	30 / 15 ¹	1 ½	<input type="checkbox"/>	<input checked="" type="checkbox"/>
LOX	790	250	163 / -297	91	3	<input checked="" type="checkbox"/>	<input type="checkbox"/>
LM	790	250	201 / -258	34	3	<input checked="" type="checkbox"/>	<input type="checkbox"/>

1. Tank MAWP

2. Flow rate based on 25 ft/sec line velocity

Table 3.3.3.2 Cell 2 Commodity Supply Capabilities

3.3.3.3 Commodity Storage Capacities and Capabilities

This section summarizes the supply and storage capabilities of the E-3 facility. The following table contains a complete listing of E-3 facility pressure vessels.

Vessel Number	Vessel Commodity	Location	MAWP (psig)	Volume (gallon)
V-271-LO	LOX/LN ₂	Cell 1	60	600
V-272-LO	LOX/LN ₂	Cell 1	2,000	100
V-187-JP	JP/RP-1	Cell 1	3,000	250
V-479- H ₂ O ₂	H ₂ O ₂ /LOX ¹	Cell 1	3,500	500
V-230- H ₂ O ₂	H ₂ O ₂ /LOX ¹	Cells 2	3,000	500
V-186-JP	JP	Cells 2	3,000	250

Vessel Number	Vessel Commodity	Location	MAWP (psig)	Volume (gallon)
V-478-JP	JP	Cells 2	3,500	1,000
V-496-LM	LM	Cell 2	60	2,000
V-516-LO	LOX	Cell 1/Cell 2	60	2,000
V-4775-8	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-10	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-11	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-39	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-40	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-41	GN ₂ /GHe	E3	6,000	21.7 ft ³
V-4775-42	GN ₂ /GHe	E3	6,000	21.7 ft ³

1. Vessels are single wall, but can be insulated for cryogenic service.
2. Vessels are initially cleaned to Level 2X, but are maintained at a Level 3 cleanliness level. Run systems between the final filter and test article interface are maintained at Level 2X.
3. Vessels are initially cleaned to Level 1XX and are then passivated for H₂O₂ service.

Table 3.3.3.3.1 E-3 Facility Pressure Vessels

3.3.3.3.1 Liquid Oxygen (LOX)

A 600 gallon LOX vessel provides storage capacity for the 100 gallon LOX run tank at Cell 1.

3.3.3.3.2 Gaseous Hydrogen (GH₂)

Sitewide GH₂ supply is available at E-3 up to 4,000 psig.

3.3.3.3.3 Gaseous Nitrogen (GN₂)

Sitewide GN₂ supply is available at E-3 up to 4,400 psig, regulated down to 3,000 psig at the test cells. In addition, GN₂ can also be supplied by tube bank trailers.

3.3.3.3.4 Gaseous Helium (GHe)

Sitewide GHe supply is available at E-3 up to 4,500 psig. In addition, GHe can also be supplied by tube bank trailers.

3.3.3.3.5 Inert Gas Storage

The storage system provides 150 ft³ of inert gas at a maximum pressure of 6000 psig and a maximum flowrate of 50 lbm/sec. Additional volume of inert gases can be supplied by tube bank trailers.

3.3.3.3.6 Hydrogen Peroxide (H₂O₂)

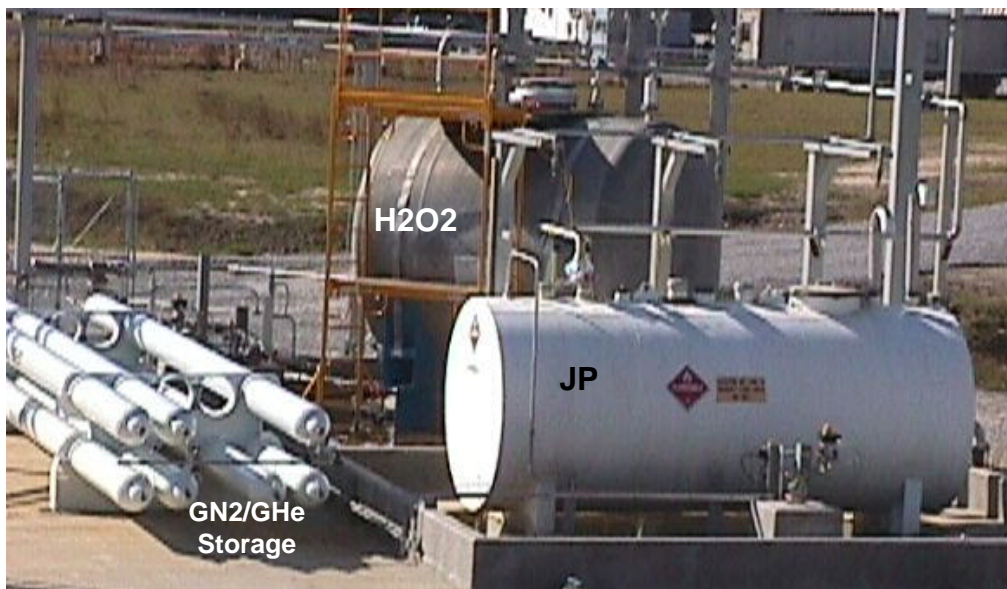
H₂O₂ is currently supplied in 30/55 gal drums. For its storage, a covered concrete pad with spill containment and deluge water coverage is located west of the test cells. A remote transfer system has been integrated into the E-3 facilities in order to fill run tanks without disconnecting the operating piping system. As part of this transfer system, two tanks with usable volumes of 3500 gal and 4000 gal can be used to store H₂O₂ as well remotely fill the Cell 1 and Cell 2 run tanks. Primary H₂O₂ liquid discharges for both cells will be routed to a 4500 gal catch tank and then sent through a catalyst bed for decomposition prior to discharge in the containment tank.

3.3.3.3.7 Hydrocarbon Fuel (JP)

JP is currently supplied from a 500 gal portable tank. Primary fuel discharges will be routed from each cell to a 3000 gal catch tank. The fuel can then be pumped into the 500 gal portable tank and reused for additional tests.

3.3.3.3.8 Gaseous Oxygen (GOX)

GOX is supplied from K-bottles.



E3 Inert Gas Storage, H₂O₂ & JP-8 Catch Tanks

Vessel Number	Description	Max Pressure (psig)	Volume
V-271-LO	LOX	60	600 gal
V-4775-XX ¹	GN ₂	6000	151.9 ft ³
V-501-H ₂ O ₂	H ₂ O ₂ Storage	ATM	3500 gal
V-502-H ₂ O ₂	H ₂ O ₂ Storage	ATM	4000 gal
V-500-H ₂ O ₂	H ₂ O ₂ Catch Tank	ATM	4500 gal
V-499-JP8	JP8 Catch Tank	ATM	3000 gal
V-504-DI	DI Water Storage	ATM	2800 gal

1. GN₂ storage consists of 7 individual bottles, each with a volume of 21.7 ft³

Table 3.3.3.3.2 E-3 Commodity Storage Capabilities

3.3.3.3.9 Master Facility Panel

The Master Facility Panel (MFP) consists of numerous regulator stations to provide gases at different pressures to meet the need of various facility systems. Details of the MFP can be obtained by contacting the Facility Manager of the E-1 Test Stand.

3.3.3.4 Electrical Systems

The capabilities described below are for test cell 1 and 2.

3.3.3.4.1 Control System

The E-3 TCC located in the E-Complex TOB, serves as the central command for the test conductor and test personnel during test operations. The process control information is monitored on TCC computer screens running WonderWare Operator Interface (OI) software.

An E-3 SCB, located near the test stands, houses two PLC control systems; one for test facility operations and one for the test article. These control systems provide real time control of facility propellant transfers, tank pressurizations, test article coolant, ignition, and propellants flows. The test article control system automatically cycles the control valves through a series of predetermined states specified by the customer. Test article blue line limit monitoring is performed by this control system. Test article redline parameters are monitored by a computer, which is interfaced to the test article control system through discrete signals. Data from the control systems are time tagged with IRIG B and stored for real-time display and posttest analysis.

The control system can provide measurement and control channels (each cell) for a test article, see details on the next page:

- 50 analog inputs for pressure, RTD, strain, or acceleration measurement
- 64 measurements for thermocouples
- 80 discrete control valves
- 20 variable control valves (16 are set up for hydraulic actuation; 4 are set up for pneumatic actuation)
- 96 discrete indications

3.3.3.4.2 Instrumentation

Facility instrumentation is installed for real time display of facility processes and data recording. Instrumentation provided for the test article will be determined with each customer. The facility also provides the ability to display real-time test article measurements. Each measurement is sampled and stored at 250 samples/second. Instruments that provide test article response information, time critical control functions, or are located at facility to test article interfaces have a typical 5 to 250 ms response depending on the specific instrument.

3.3.3.4.3 High Speed Data Acquisition System

The High Speed DAS (HSDAS) has a high speed 16 bit digitizer and recorder. The digitizer can be configured as follows:

- 62 channels at 50 K SPS (22.5 K Hz)
- 32 channels at 100 K SPS (45.5 K Hz)
- 16 channels at 200 K SPS (80 K Hz)

Typically, the digitizer is configured for 32 channels at 100 K SPS per channel. The data is recorded digitally on Super VHS tape. One channel is reserved for IRIG B for time correction. A second channel is typically used for Time zero (start of test). Event channels are also available.

3.3.3.4.4 Low Speed Data Acquisition System

The LSDAS system has a 128 channel digitizer per cell that share 100 (50 per test cell, but patchable) programmable bridge type signal conditioners. The system provides 16 bits of resolution with a throughput of 200 SPS. These systems provide reconfiguration flexibility and hardware/software common with other existing test systems. An auto calibration capability also provides the ability to verify the systems, using a NIST traceable standard.

3.3.3.4.5 Data Processing

Data processing is provided for the LSDAS and HSDAS. The LSDAS data is converted to Engineering units and processed into the E Complex WinPlot file format. WinPlot is a NASA-developed program for plotting measurement and calculated values.

A program for quickly viewing post-test data is also available. Data is provided on digital audio tape or CD-ROM formats.

The HSDAS data is available in both time domain and frequency domain formats. Digital filtering algorithms are available for processing. Data is provided on CD ROM for processed data and Super VHS for raw dynamic data.

Provisions can be made for specialty instrumentation such as Optical Deflectometers and Speed Sensors.

Posttest, off -site data transfer is available for both systems through the Internet. Data security is provided through password protection. Data encryption is also available.

3.3.3.4.6 Power

AC - The facility power system provides single and three-phase power at 480 VAC, 277 VAC, 208 VAC, 220 VAC, and 120 VAC. Uninterruptible power supply (UPS) systems provide a minimum of ten minutes of 120 VAC power to test critical systems.

DC - 28 V DC is provided for control system I/O.

3.3.3.4.7 Video Systems

E-3 utilizes eight low speed video cameras for normal testing. Cameras 1, 3, and 4 are permanently mounted to the canopy columns of Cell 1 at the Northwest, Northeast, and Southwest columns respectively. Camera 2 is portable. There is one portable high speed camera available at the test stand. It is capable of recording up to 500 frames per second. Each camera (both high and low speed) has pan, zoom, focus, iris, and tilt capabilities. The camera enclosures, boxes, and conduits are purged with GN₂ to maintain compliance with the appropriate electrical hazardous classification requirements. There are also four portable IR cameras available for use.

3.3.3.5 Ancillary Facility Systems

3.3.3.5.1 Deluge System and DI Water

The E-3 deluge system, consisting of spray nozzles, covers all existing test cells, oxidizer vessels, fuel vessels, the Cell 2 flame bucket, the containment tank and all tanker fill headers. The supply system has been integrated with the E-Complex deluge water supply system as part of the facility upgrades. E-3 also uses a 6 inch potable water system for the purpose of providing deluge cooling water to two water cannons situated between Cell 1 and Cell 2. All areas can be remotely operated from the control room. In addition, the two water cannons can be locally operated. This system will limit damage in the event of a fire in a test cell or propellant storage/handling area as well as provide a means to dilute H₂O₂ in case of an emergency situation.

A DI water system is installed for flushing H₂O₂ run tank and run lines. DI water for this system is provided by a portable skid and stored in a 2800 gal tank.

3.3.3.5.2 Plume Impingement Area

Plume impingement areas are provided for both Cell 1 and Cell 2. The areas feature thrust deflectors that are made of refractory concrete ablative material for the purpose of minimizing the effects of heat and acoustic loads generated by a combustion device plume. The material has excellent thermal properties for high temperature applications.

In Cell 1, the plume impingement area extends northward from the test stand. The plume is deflected away from the concrete foundation and metal grate that form the floor of this test cell. High heat-load test articles are positioned such that the nozzle exit area for plume is outside the main cell structures.

In Cell 2, the plume is directed first downward into the flame bucket and then redirected northward. For this purpose, the plume impingement area at the bottom of the flame bucket is sloped.

3.3.3.5.3 Hydraulics

The E-3 facility is equipped with a 3,000 psig hydraulic system for actuating facility and special test equipment valves.

3.3.3.5.4 Communications

The E-3 facility is equipped with headset communication boxes in numerous locations to allow voice communication between the TCC and the test facility during operations. The facility is also outfitted with an intercom system.

3.3.3.5.5 H₂O₂ Vapor Monitoring

A remote H₂O₂ Vapor Monitoring System will be integrated into the E-3 test area as part of the facility upgrades.

3.3.3.5.6 H₂O₂ Containment

A 100,000 gal containment pond for H₂O₂ discharge and dilution has been built and integrated into the E-3 Test Facility to support test programs and commodity bulk storage.

3.3.3.5.7 H₂O₂ Enrichment Facility

The Hydrogen Peroxide Enrichment Skid is a transportable processing plant that enriches aerospace grade H₂O₂ from 90% to 98% final concentration. The Skid is a self contained unit that houses all of the tanks, lines, coolants, crystallizers, instrumentation

and program logic controllers to perform the concentration operation nearly autonomously. The unit is located near E-3, positioned on a concrete slab, but it is possible for it to be relocated for remote use.

3.3.4 E-4 Test Facility

The newest addition to the E-Complex will be the E-4 Test Facility. The E-4 Test Facility will be capable of providing a low-pressure supply of JP-7 and LOX to test articles having a thrust in the horizontal plane up to 50,000 lbf (maximum). The facility's design is especially suited for the testing of Rocket Based Combined Cycle (RBCC) test articles.

The E-4 Test Facility design also allows for the growth of test capabilities to meet future testing requirements of RBCC and potentially other engine concepts. The future development of the E-4 Test Facility is envisioned to occur as follows:

- 1) The incorporation of an LH_2 and an H_2O_2 propellant supply capability to support the testing of power packs and engine systems up to 50,000 lbf thrust (maximum).
- 2) The addition of a Ram Air test capability up to Mach number 0.8 for engine systems having a maximum thrust of 50,000 lbf.
- 3) Upgrading the necessary propellant and structural entities to support the testing of power packs and engine systems up to 500,000 lbf thrust (maximum).

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4.0 PROPULSION TEST SUPPORT

SSC maintains a number of facilities and provides specialized services required for the direct support and operation of test facilities. Included are the Cryogenic Propellant Storage Facility, High Pressure Gas Facility (HPGF), High Pressure Industrial Water (HPIW) Facility, emergency power-generation facilities, and electrical distribution systems. Additional information related to propulsion test support facilities and services is provided in the following sections.

4.1 Cryogenics Operations [11,24]

Cryogenics Operations provide LOX and LH₂ for the engine testing programs at A and B Complex that require liquid propellants. This support includes operating and maintaining a LH₂ Storage and Transfer Facility, a LOX Transfer Facility, three LH₂, and six LOX barges. The LH₂ barges can be filled at the LH₂ Storage and Transfer Facility from the storage sphere or directly from tank trailers through six off-loading stations. The six LOX barges are filled at the LOX Transfer Facility directly from the tank trailers through the six off loading stations. The Cryogenics Operations technicians provide standby and real time support to ensure all LOX and LH₂ facilities, barges, and equipment are ready and function properly for engine testing. They also perform propellant sampling, vessel certification, calibration, preventive maintenance, vacuum maintenance, and corrective maintenance.

4.1.1 Liquid Oxygen Service

LOX services at the Cryogenics Operations area include transfer operations from vendor delivery trailers to SSC storage barges and barge-to-barge transfer. Additional details related to LOX transfer operations and storage barges are provided in the following sections.



Liquid Oxygen Storage and Transfer Facility

4.1.1.1 Transfer Operations

Delivery of LOX to the Cryogenics Operations area storage and transfer facility at the cryogenic propellant dock is supplied by vendor tank trucks. There are two stations, each with three trailer positions, at the dock for off-loading LOX from vendor trucks. The trucks each contain approximately 4,400 gal. and are off-loaded via 3 in. flex hoses, which are connected to a single 8 in. pipe that connects to each LOX barge position. Off-loading time per trailer averages 1 hour (hr) and 30 min, with simultaneous downloading of up to six trailers. Each position can be isolated by a series of valves that allow each barge to be singularly filled from the vendor trucks at 20 - 30 psig per truck, or to transfer LOX from one barge to another during topping or downloading operations. A vaporizer on each vendor tank truck is used to pressurize the trailer storage tank to 20 - 30 psig and thus transfer LOX to a LOX barge.

4.1.1.2 Storage Barges (52,53)

Six LOX transfer barges are used to transport LOX from the Cryogenic Operations area to the Test Complexes. Dock facilities for two barges exist at the A-1 and A-2 test stands, and docking facilities for three barges exist at the B-1/B-2 test stand. Two additional barge positions are available at the "B" Test Complex, but have no piping or mooring devices.

Each barge has a total storage capacity of 105,000 gal gross of LOX with 95,000 gal usable at 40 psig. Barge-mounted pumps transfer LOX from the barges through the dock transfer system into the test stand storage/run tanks. The barges are also used to receive LOX from the storage/run tanks in the event they have to be emptied. The barge's capabilities are listed below.

- a. Two transfer pumps rated at 1,250 gal/min, each at 250-350 psig, nominal capacity at 3,600 revolutions per minute (rpm) for a total pumping capacity of 2,500 gal/min.
- b. Onboard GN₂ storage sufficient to provide for necessary valve operations and purging.
- c. A deluge system supplying industrial water for fire protection. Water for this system is available when the barge is docked at the storage facility or the test stands.
- d. Barge-to-dock connections for LOX transfer including:
 - (1) Main transfer line
 - (2) Control and instrumentation
 - (3) Main pump's electrical power

- (4) GN₂ supply at 2,250 psig dockside, reduced to 750 psig on barge (for control-valve operations)
- (5) Barge electric power system
- (6) Deluge water system.

4.1.2 Liquid Hydrogen Service

LH₂ services at the Cryogenics Operations area include transfer operations from trailer truck to storage sphere, transfer operations from storage sphere to barge, transfer operations from vendor delivery trailers to SSC storage barges, barge-to-barge LH₂ transfer, and barge docking. Additional details related to LH₂ transfer operations and storage barges are provided in the following sections.

4.1.2.1 Transfer Operations

Provisions for delivery of LH₂ by barges or trailer trucks are available at the LH₂ storage and transfer facility in the Cryogenics Operations area. The facility consists of six trailer transfer stations, a 600,000 gallon storage sphere, and three barge docks. Two barge docks are complete transfer facilities, while one requires facility interfaces to be completed for the liquid transfer line, vent line, deluge water, and associated controls. Six vendor trailers can off-load simultaneously at 40-60 psig via 2 in. flexhoses connected to a 4 in. header. The 4 in. header connects to an 8 in. sphere/barge transfer line. Off-loading of vendor trailers averages one hr and 10 min with each trailer containing approximately 12,000 gallons of liquid. Total connect, off-load, and disconnect takes approximately two hrs and 30 min. Transfer rate per trailer is approximately 200 GPM. A vaporizer on each vendor trailer is used to pressurize the trailer storage tank to 40-60 psig and to move LH₂ to the storage sphere or barge.

Barges can be filled directly from trailers or the storage sphere. Pressure transfer from the sphere to barge is at 9 psig with a flow rate of approximately 3,000 GPM. Barge loading takes approximately one hr and 30 min. Total connect, load, sample, and disconnect takes about nine hours. Barges can also be off-loaded into the sphere in case of emergency. Barge to barge transfer is also available.

4.1.2.2 Storage Barges (54)

Three LH₂ transfer barges are used to transport LH₂ from the LH storage and transfer facility to storage/run tanks at the A-1, A-2, and B-1/B-2 test stands. Each barge has a total capacity of 270,000 gal and a usable capacity of 240,000 gal at 70 psig. A barge-mounted LH₂ vaporizer provides ullage pressure (60-70 psig) to transfer LH₂ from the barge through the test stand dock-transfer facilities to the storage/run tank at a nominal flow rate of 5,000 gal/min. The barge can also be used to receive LH₂ from the

storage/run tank at an approximate rate of 3,500 gal/min in the event the tank has to be emptied. Each barge is equipped with the following:

- a. One LH₂ vaporizer rated at 92.3 psig design pressure and 4,320 pounds per hour (lb/hr) at 70 psig.
- b. Onboard GN₂ storage sufficient to provide for necessary valve operations and purging during transit on-site (5 hr transit to and from the vendor's facility, if required).
- c. One deluge system requiring 4,400 gal/min of industrial water at 80 psig for fire protection. Deluge system hookup is available at each test stand docking area and at the LH₂ storage and transfer facility.
- d. Barge-to-dock connections, which interface with the following dockside systems during LH₂ transfer:
 - (1) Main transfer line
 - (2) GH₂ gas vent line
 - (3) GN₂ purge system at 2,250 psig dockside, reduced to 750 psig on barge
 - (4) Deluge water system
 - (5) Control and instrumentation
 - (6) Electrical power supply
 - (7) Electrical grounding system

4.2 High Pressure Gas Facility [4,24,27,37,38,42,43](101)

The HPGF receives, stores, and distributes the high pressure gases required to support engine testing programs and other SSC-assigned missions. The HPGF supplies High Pressure Air (HPA), GHe, GN₂, and GH₂ to the A, B, and E Complexes. The facility also provides GH₂ to the hydrogen battery areas.

The HPGF support is scheduled on a two-shift basis providing operations, preventive and corrective maintenance, and periodic sampling, certification, and calibration (systems, subsystems, and components). Additional information relating to the HPGF is contained in the sections that follow.

4.2.1 Air Supply System (46)

The HPA system is designed to produce missile-grade air. System pressure is maintained between a minimum of 1,500 psig and a maximum pressure of 2,800 psig; MDWP is 3,500 psig.

Atmospheric air is supplied by individual, oil bath filters at the roof level of the HPGF. Atmospheric air is compressed by two identical Clark compressors and three Cooper

compressors. Each compressor is rated for 850 SCFM at 3,500 psig, powered by 500 horsepower (hp) electric motors. Only three compressors can be run simultaneously.



Cooper Compressor at HPGF

Two air-drying filtering systems are interconnected to allow any compressor to discharge to either system. An absorption unit consists of beaded activated charcoal to remove hydrocarbons and compressor oil. An air dryer (Lectrodryer) consists of two high pressure containers filled with desiccant beads to remove moisture. Air is dried to -65°F dew point at 1 atm or the ppmv equivalent. One tower removes moisture while the other tower regenerates. The Regeneration process uses 300 SCFM.

The air is filtered through a bank of wafer, felt-type, 20 μ filters and a set of 20 μ sintered backup filters to remove accumulated particles. The missile-grade air is then distributed to a manifold. The manifold is connected with a 3 in. diameter transfer line to the site-wide systems at each test complex. The system pressure is maintained by automatic cycling. HPA is stored at individual site locations and maintained at pressure via cross-country gas supply from the HPGF.

4.2.2 Helium Supply System [24](40,41)

The high pressure He system is designed to produce high pressure helium with a dew point of -100 °F minimum, and a maximum hydrocarbon content of 10 ppm by weight. System pressure is maintained between a minimum 2,000 psig and a maximum 4,500 psig with an MDWP of 4,500 psig.

GHe is delivered to SSC in tube bank trailers and off-loaded into two low pressure storage vessels at the HPGF. The table provides storage capacity and working pressure for each vessel.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (ft³)	Storage at 450 psig, 70 ° F (scf)
V-20-HE	520	450	10,000	350,000
V-21-HE	498	450	10,000	350,000

Table 4.2.2 Helium Vessel Storage Capacity and Working Pressure

HP GHe is provided to the site-wide systems by compression of GHe from the storage vessels. Two identical Henderson compressors, each rated for 250 – 400 ft³/min at 6,000 psig, discharge to a common header. One Clark, primarily used for backup, also discharges to the common header. It is an oil-lubricated, reciprocating compressor, rated for 200 ft³/min at 6,000 psig, driven by a 125 hp electric motor. The GHe is passed through a separator and an adsorber to remove oil contaminants. The GHe is then filtered through a 20-μ filter and three, parallel, molecular sieve, cartridge-type purifiers that remove water vapor. The GHe is then distributed to the site-wide systems. Excess trailer-supply GHe is transferred directly into the high pressure GHe system, using the same process as the transfer from low pressure storage. The GHe is then distributed through a 1 1/2 inch diameter transfer line to the site-wide systems.

The system pressure is maintained via operator observation by manually starting and stopping the compressors. All high pressure GHe is stored at individual site locations and maintained at pressure via the cross-country gas supply from the HPGF.

4.2.3 Nitrogen Supply System [24](28-31)

The high pressure GN₂ system is designed to produce high pressure GN₂ with system pressure maintained between a minimum of 2,400 psig and a maximum of 4,400 psig with an MDWP at 6,000 psig. LN₂ is delivered to SSC by vendor tank trucks and off-loaded through 40 μ filters into two LP storage vessels at the HPGF. The LN₂ transfer is performed by vendor tank truck self-pressurization systems or with facility pumps [two pumps, each rated for 125 GPM at 15 psig suction and 50 psig discharge; 100 psig maximum suction pressure (P1LN and P2LN), driven by 5 hp electric motors]. The following table provides storage capacity and working pressure for each vessel.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-112-LN	33 (ullage)	33 (ullage)	63,250
V-173-LN	25 (ullage)	25 (ullage)	27,000

Table 4.2.3 Nitrogen Vessel Storage Capacity and Working Pressure

The low pressure storage vessels are maintained at a standby pressure of 2-3 psig, with a maximum working pressure of 22-25 psig during operations. LN₂ (from the storage vessels) is pumped with three centrifugal booster pumps (each rated for 60

gal/min) at 65-75 psig, which are driven by 7.5 hp electric motors, through a 40 μ filter, to the suction of five Kobe positive-displacement pumps (each rated for 15.6 gal/min at 6,000 psig), which are driven by 60 hp electric motors. The Kobe pumps discharge through four aluminum-finned, ambient-air vaporizers; each rated at 4017 SCFM at 6000 psig. The GN₂ is then distributed through a 4 in. diameter transfer line to a manifold. The site-wide systems can draw GN₂ from this manifold.

The system pressure is maintained via operator observation by starting and stopping the pump systems. All high pressure GN₂ is stored at individual site locations and maintained at pressure via the cross-country gas supply from the HPGF.



Kobe Pumps at HPGF

4.2.4 Hydrogen Supply System (7-9)

The high pressure GH₂ system is designed to produce HP GH₂ with the system pressure maintained between a minimum of 2,200 psig and a maximum of 3,000 psig with an MDWP of 6,000 psig, currently limited to 4,000 psig by LH₂ pumps.

LH₂ is delivered to SSC by vendor tank trucks and off-loaded into the HPGF LP storage vessel. The LH₂ transfer is performed by the vendor tank truck self-pressurization systems or with onboard tank truck pumps. The storage capacity and maximum allowable working pressure for the HPGF LP vessel is in the following table.

Vessel Locator Number	MDWP (psig)	Certified Pressure (psig)	Water Volume (gal)
V-267-LH	150 (ullage)	150	20,000

Table 4.2.4 LH₂ Vessel Storage Capacity and Working Pressure

The low pressure storage vessel is maintained at a maximum working pressure of 95-100 psig. LH₂ from the storage vessel is pumped with two, cryogenic, vacuum-jacketed, reciprocating pumps (each rated for 5.2 gal/min at 4,000 psig, driven by 30 hp electric motors) through aluminum-finned, ambient-air vaporizers (each rated for 35,000

ft³/hr at 4,000 psig). The GH₂ is then distributed through a 2 in. diameter transfer line to the site-wide systems.

The system pressure is maintained automatically by a PLC-based control system operating the pumping equipment. All high pressure GH₂ is stored at individual site locations and maintained at pressure via the cross-country gas supply from the HPGF.



Hydrogen Storage Tank at HPGF

4.2.5 Auxiliary Tube Bank Storage

There are six movable, trailer-mounted tube bank storage vessels that are used at locations having no permanent high pressure gas supply. The tube bank trailers can be used to store HPA, GHe, or GN₂. The tube bank trailer numbers and design capacities are given in the following chart.

Trailer Number	Gas Service	Design Capacity (scf of air)
91-1	GHe/HPA/GN ₂	78,000 scf at 6,000 psig
91-2	GHe/HPA/GN ₂	78,000 scf at 6,000 psig
91-3	GHe/HPA/GN ₂	78,000 scf at 6,000 psig
91-4	GHe/HPA/GN ₂	78,000 scf at 6,000 psig
1589	GHe/HPA/GN ₂	48,400 scf at 3,600 psig
1597	GHe/HPA/GN ₂	48,400 scf at 3,600 psig

Table 4.2.5 Tube Bank Trailers



Tube Bank Trailers at HPGF

4.3 High Pressure Industrial Water Facility [3,4]

The HPIW facility furnishes water to the "A" and "B" Test Complexes for test stand deflector coolant, fire protection (deluge), and diffuser operation (A-1, A-2 and B-1). It also furnishes water for fire protection of the propellant barges (LH₂) at the test stands. The HPIW facility also houses electrical power-generation equipment for backup supply to the A and B Complexes. Additional information relating to the HPIW facility is contained in the following sections.



SSC High Pressure Water Facility

4.3.1 Industrial Water System [4]

Four pumps, with a capacity of 5,000 gal/min per pump, supply an 800 ft. diameter, 66 million gallon reservoir (26 M-gal usable), via a 42 in. diameter transfer line from the main access canal. The reservoir can also be supplied from three deep wells, two of which are currently downmoded.

The HPIW pumping system consists of two electric motor-driven pumps and 10 diesel motor-driven pumps. One electric motor-driven pump serves as a jockey pump to maintain system pressure during non-supply operations. The jockey pump is driven by a 50 hp motor and provides 200 gal/min at a 495 ft. discharge head. The other electric motor-driven pump is driven by a 500 hp motor and provides 3,000 gal/min at a 495 ft.

discharge head to supply small usages (e.g., test stand run tank fire protection, barge deluge). The 10 diesel motor-driven pumps are single-stage, double suction, centrifugal pumps, with individual ratings of 33,385 gal/min at a 495 ft. discharge head (225 psig) when operating at 480 rpm. Diesel fuel storage consists of two 25,000 gal double-wall tanks, which are sufficient to provide a 20 hr. supply with all engines operating at their rated load.

Supply from eight of the HPIW pumps is discharged into an 84 in. diameter manifold, and pumps 9 and 10 discharge into a 112 in. diameter manifold, which supplies a 75 in. diameter transfer line (flow rate: 212,000 gal/min) to the "A" Test Complex and a 96 in. diameter transfer line (flow rate: 290,000 gal/min) to the "B" Test Complex. The 75 in. diameter transfer line to the "A" Test Complex is branched to two 66 in. diameter lines, one each to the A-1 and A-2 test stands. Four additional stub-outs exist in the 112 in. diameter manifold.

At T minus 1 hr. of a test countdown, the pumps are powered-up for the test stands as follows: seven pumps for A-1, eight pumps for A-2, and nine pumps for B-1 and B-2.



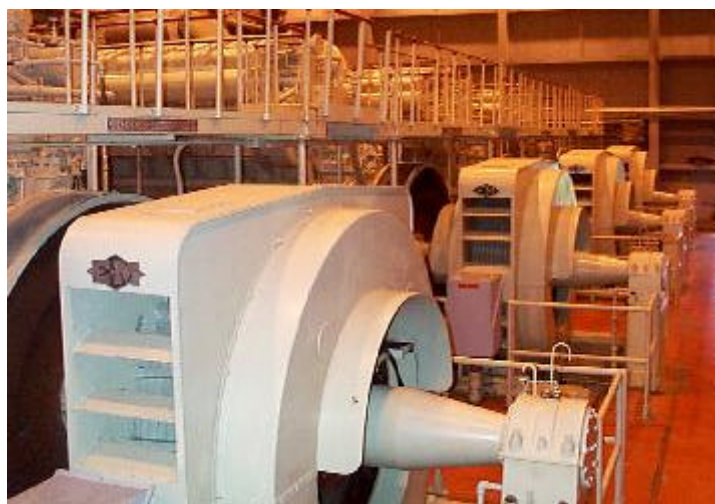
1 of 10 HPIW Pumps



10 Nordberg Diesel Engines That Drive Pumps

4.3.2 Emergency Power-Generating System [4]

The HPIW emergency power-generating system is capable of providing emergency electrical power to the Test Complex (A-1, A-2, and B-1/B-2 test stands, TCCs, and the Bldg 4995). There are four, 1875 kVA [1500 kilowatt (kW)], diesel-driven generators located at the HPIW Facility. These four generators can be synchronized with, or operated independently of, the utility-fed circuits 11 and 21 feeders that source only the Test Complex. The emergency generators are used when the frequency or stability of utility power is threatened by inclement weather. The Test Conductor or Instrumentation personnel request generator support. These generators are rated to support the Test Complex until all post-test operations are complete.



Four Diesel-Driven Generators at HPIW

4.4 Site Electrical Distribution [13](51)

SSC's electrical service is supplied by two 115 kV utility lines feeding the double-ended, 13.8 kV main substation at the south side of the site. Each 115 kV line feeds a 35 MVA transformer. The secondaries of the two 35 MVA transformers are designed to be normally separated, but can be tied together with a tie circuit breaker. The two secondaries each feed a group of 13.8 kV feeder circuit breakers (assigned in dual pairs).

SSC A and B Complex distribution circuits are run as dual circuits, with an automatic or manual transfer system at the load ends, which permits rapid restoration of service if one of the feeders should fail. Each of the 13.8 kV, feeder circuit breakers' trip circuits is set at approximately 400 amperes, permitting a maximum load of about 9500 kVA from any 13.8 kV feeder.

The dual-feed system will support the entire connected electrical load from one feeder, if required. See Table 4.4-1 for transformer ratings.

Identifier	Capacity Out (kVA)	Voltage In (kV)	Voltage Out (V)
1	35,000	115	13,800
2	Removed	Removed	Removed
3	1500	13.8	480
4	1000	13.8	480
5	750	13.8	480
6	500	13.8	480
7	300	13.8	480
8	30	13.8	208
9	3750	13.8	4,160
10	500	13.8	2,400
11	500	13.8	480
12	2000	13.8	480

Table 4.4-1 Transformer Ratings

5.0 TEST OPERATIONS SERVICES

The Test Operations Contractor (TOC) provides on-site support to NASA and the resident agencies at SSC. Areas of support relating to propulsion testing include Test Stand Operations, Test Engineering, Systems Engineering Analysis and Simulation, Mechanical and Electrical Engineering Design, Configuration Management, Technology Development, Program Management Support, Scheduling Support, and Safety & Mission Assurance (S&MA).

5.1 Test Stand Operations

Test Stand Operations consist of engineering and technical test teams, which can, at the discretion of the facility owner or test article manufacturer, process and install test articles, conduct tests, and remove test articles. This support also provides corrective and preventative maintenance support on technical systems and test complex specific systems, to implement local, major Construction of Facility (C of F), and commercial “demand” type refurbishment/modification projects that make programmatic and facility upgrade changes to test and technical systems. Operations teams configure test facilities, control systems, instrumentation, and data acquisition systems for test firings. During test firings, additional support personnel are provided to setup electronic controls, instrumentation, and electrical systems. They also perform post-test data processing, data analyses, and data validation for data package delivery to the test program customers.

A separate group provides direct access to sampled propellants, pressurants, and consumables required to meet test customer needs. These include, but are not limited to Liquid and Gaseous Hydrogen and Oxygen, Nitrogen, Helium, Diesel, and Water. The Hydrogen and Oxygen are provided to the A & B test stands by barge and can accommodate extended run durations on a broad family of rocket engines.

5.2 Test Engineering

Test Engineering provides mechanical and electrical engineering services to Maintenance and Operations at the test complexes and supporting facilities that are used for preparing and testing liquid, solid, and hybrid propulsion systems, components, and special equipment at SSC. These services involve: establishing and supporting preventive and corrective maintenance activities; design review for refurbishment and/or modification of technical facilities on local and major C of F projects; support during fabrication, installation and activation of test facilities; support on anomaly investigations and safety hazard analyses.

5.3 Engineering Design

Engineering design support is provided to adequately incorporate test articles into the test facilities and ensure test article performance is captured during test operations. Engineering design drawings and various technical data in electronic format are readily

produced for various test facility propulsion systems, data acquisition and control, power distribution, and test article and facility instrumentation. Much of the test article/test facility interface control cables, data acquisition cabinets, and power distribution are developed in a “cradle to grave” fashion to ensure accurate system performance. Mechanical systems design and support activities are typically limited to the production of design documentation to allow for competitive fabrication/installation subcontracting by others.

5.4 Systems Engineering Analysis and Simulation

Test article performance is of the utmost importance to accurately predict the mission suitability of the given article. Test articles have performance requirements that must be met during test operations and facility performance is a key to successful testing. Utilizing flow analysis tools, such as RPTA, system engineering develops mathematical simulation models of test propulsion systems to accurately predict the facility performance during a particular test. Data acquired during a particular test is analyzed to determine simulation model accuracy and required model modifications. Continuous improvement in simulation tools to increase predictive techniques is an ongoing process. In some case, computational fluid dynamics models are developed to understand specific physical performance parameters. Data from these CFD models is utilized to develop simple constitutive models to be utilized in simple, fast runtime simulation tools.

5.5 Configuration Management

In order to provide accurate and current engineering information pertaining to existing test systems in a dynamic environment, a robust configuration management activity is provided in accordance with the industry-wide CM II methodologies. The configuration management activity has complete responsibility for providing current electronic format drawings and supporting technical information for the test systems associated with the E complex and partial responsibility for the A and B complex. Engineering Change Requests, Engineering Orders, configuration management audits, Configuration Control Board activities, component database entry and maintenance, and continuous improvement are all performed within the Engineering Group. Electronic media is maintained and made readily available site wide through the WindChill software system for all parties involved with utilization of test facilities.

5.6 Test and Evaluation (T&E) Technology Development

In order to support safety, effectiveness and efficiency on testing and analysis of advanced aerospace propulsion systems, as well as improving propulsion ground test facilities, research and development of new T&E technology tools is conducted. In addition, assessment, certification, and acquisition of T&E technologies from the commercial, academic, and government sector are made. The harsh nature of the rocket engine test environment creates a need for very specialized T&E technologies that will improve the test operations and provide the best possible test data. Hence, an

approach of technology identification, development or acquisition, and prototype application is typically used.

Focus areas for T&E technology R&D include:

- Integrated, intelligent system health management, including sensors, software, and pilot demonstration on ground test systems
- Rocket plume effects monitoring and prediction, including plume spectroscopy, plume acoustic measurement techniques and sensors, and plume atmospheric transmission modeling
- Computational fluid dynamics (CFD) of rocket components and test systems, including flow-meters, pumps, and valves in cryogenic fuel systems
- Advanced sensors and Instrumentation, including electro-optical instrumentation, wireless instrument systems, thermal imagery, and hydrogen leak and fire detection
- Test measurement system design & integration, data reduction and analysis, and motor specific constituents data base development.

Typifying the output of these efforts, leading edge technology has been developed that can identify specific rocket engine component problems via non-intrusive measurement of plume constituents.

5.7 Program Management Support

The Program Management Support function provides NASA with full program support functions including Program Control, Program Cost tracking, Earned Value Management, and Project Engineering. This section supplies NASA with a single point of contact for coordinating, directing and completing the required program support.

The Project Engineering function is also provided through this office. Project engineering furnishes NASA with a single point of contact for project integration and coordination of technical support to test project activities. This function is responsible for status reporting to contractor management and NASA project management on SSC projects.

5.8 Scheduling Support

This function is responsible for developing, integrating, maintaining and reporting program schedules. This team develops integrated schedules for all efforts on programs from simple cost tracking to detailed Earned Value Management schedule tracking.

5.9 Safety & Mission Assurance

Safety & Mission Assurance support consists of process oversight at the propulsion test sites and support facilities. The S&MA group develops plans and procedures in order to comply with site, local and federal regulations. The department provides training for TOC as well as other SSC contractors and NASA personnel. Support is provided for NASA injury/incident data bases as well as contractor requirements. The department controls several data bases relative to Safety Meetings and Inspections, and Work Authorizing Document reviews in order to track issues and provide metrics. The Quality Assurance side of the department issues Inspection Stamps and Certification Cards providing documentation as well as criteria for ensuring a trained workforce.

5.10 Program Integration

In order to support agency-level and center-level, cross-cutting functions and capabilities, including NASA's Rocket Propulsion Test Office, research and development of test and evaluation technologies, and implementation of performance improvements, specific program integration steps are accomplished. These include supporting focused, integrated planning and data sharing across both NASA and DoD rocket propulsion centers via the National Rocket Propulsion Test Alliance and across NASA via the Rocket Propulsion Test Management Board. This integrated planning includes assets, activities, and resources involved in development of testing and facility investments and in consolidating strategies. These integration steps also include identification and application of "best practices", lessons learned, and testing technologies across the family of rocket propulsion test centers.

5.11 Performance Improvement

Performance improvement for key project management and test and evaluation processes is critical to sustained growth, customer satisfaction, and employee satisfaction. Numerous continuous improvement tools are utilized in order to assess center programs, projects, processes, or tasks and to recommend policies, process improvements, standards, training and tools. The continuous improvement tools are drawn from the continuous improvement initiatives being applied and proven in numerous aerospace organizations in government and industry. Following the dictum of Dr. Joe Juran, "if you can't measure it, you can't improve it", strict attention is given to selection and tracking of critical metrics in order to manage technical performance, schedule, and cost for center support efforts.

6.0 LABORATORY SERVICES

Laboratory services are provided to NASA and other agencies as well as commercial organizations through the Science Laboratories, Environmental Services Laboratory, and Measurement Standards & Calibration Laboratories.

6.1 Science Laboratory Services

6.1.1 Environmental Laboratory

The Science Laboratory Services Environmental Laboratory consists of a fully equipped analytical laboratory, and facilities for research and development. Performance of the laboratory plays a critical role in determining the outcome of an investigation in terms of the accurate and precise characterization of samples submitted for analysis. The Environmental Laboratory requested and received EPA Certification in 1996. The certification consists of an annual performance-based study. Each year, the results of the study are reported to the state's certifying officer who then issues a certification status report. Currently, the laboratory is certified to perform more certifiable analyses than any other laboratory in the State of Mississippi, and is considered one of the top laboratories in Southeastern United States.

As a convenience to laboratory customers, a variety of reporting capabilities have been developed. The Environmental Laboratory produces two levels of reporting (1) Contract Laboratory Program (CLP) reports, and (2) customized level II reports which are tailored specifically to meet individual customer needs. CLP reporting follows very rigorous EPA guidelines for data quality assurance and control, which sets this level of reporting apart from the typical level II report. Most environmental laboratories do not perform to the extreme level of quality control/assurance measures required of CLP reporting.

Additional information about the SSC environmental program can be obtained from the environmental website www.ssc.nasa.gov/environmental or Stennis Procedures and Guidelines 8500.2, Environmental Operations and Implementation Program.

6.1.1.1 Environmental Capabilities

The laboratory has comprehensive experience in environmental services including:

- Chemical analysis of all environmental matrices (air, water, soils, etc.)
- Hazardous and industrial waste characterization
- Preparation and implementation of environmental sampling plans
- Lead/paint remediation analysis/study
- Oil and sludge analysis
- Flora and fauna study
- Wetland mitigation management
- Phase I and II site assessments

- Environmental GIS mapping
- Natural Resource Management

Laboratory expertise is based on in-depth knowledge of federal and state regulations and the permitting and implementing requirements established for SSC. All aspects of environmental management, from permitting assistance to sampling, analysis, and statistical evaluation are supported.

6.1.1.2 Analytical Services

The Environmental Laboratory has been responsible for the sampling and analysis of the wastewater and drinking water at SSC since its inception. The responsibility has since been expanded to include sampling and analysis of the air, groundwater, soil, and vegetation. Sample collection procedures, preparation, and analysis follow published EPA procedures and are regulated under extensive quality assurance and control programs. Statistical evaluation of the analytical data is used in meeting permitting requirements, preparation of regulatory reports, and research interpretation. The following table consists of major equipment items and the capabilities gained from them.

INSTRUMENT	FUNCTION
Gas Chromatograph (3)	Used to determine part-per-billion (ppb) level concentrations of herbicides, pesticides, polychlorinated BI-phenols (PCBs), and total petroleum hydrocarbon (TPH)
Gas Chromatograph/Mass Spectrometer (2)	Allows for the analysis of soil, water and air for volatiles and semi-volatile compounds
Atomic Absorption Spectrometer	Allows for the analysis of most environmental matrices for metals and cations
Inductively Coupled Plasma Spectrometer (2)	Analysis of trace metals in soil, water, air, etc.
Ion Liquid Chromatograph	Used to determine anion concentrations in drinking water, wastewater, and hydrogen peroxide Perchlorate determination
(2) High Pressure Liquid Chromatography systems which utilize (3) different technologies of detectors; UV detector, fluorescence detector, and a photodiode array detector	Pigment concentrations Analysis for explosives Herbicide analysis; diquat and paraquat Pesticide analysis; glyphosate Carbamates

INSTRUMENT	FUNCTION
Mercury Analyzer	Low level mercury in water/food; ppb level analysis
Flow-injection Ion Analyzer	Total N ₂ , ammonia
UV/VIS Spectrophotometer	Quantitative Filter technique applications for the determination of pigment concentrations present in suspended particles in ocean water Pigment concentrations of dissolved organic matter in ocean water Pigment concentrations in plant life
Pensky-Martens Closed Flash Point Tester	Flash Point determination of wastewater

Table 6.1.1.2 Environmental Laboratory Capabilities

Additional general support equipment includes balances, autoclaves, centrifuges, pH meters, turbidity meters, dissolved-oxygen meters, temperature and specific conductivity probes, total suspended particulate monitors, particulate matter of 10-m material (PM-10) monitors, composite surface-water samplers, and ground-water monitoring equipment.

6.1.1.3 Regulatory Authorities

All analyses performed by the Environmental Laboratory conform to strict requirements of:

- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
- National Polluting Discharge Elimination Systems (NPDES)
- National Primary Drinking Water Regulations (NPDWR)
- Resource Conservation and Recovery Act (RCRA)
- Safe Drinking Water Act (SDWA)
- Clean Water Act (CWA)
- Clean Air Act (CAA)

6.1.1.4 Analytical Parameters and Methods

Analytical Parameters	Method	Analytical Parameters	Method
Biochemical Oxygen Demand	405.1	Carbamates	531.1
Chemical Oxygen Demand	410.4	Glyphosate	547
Oil and Grease	1664	Diquat	549.1
Settleable Solids	160.5	TPH	8015

Analytical Parameters	Method	Analytical Parameters	Method
Total Suspended Solids	160.2	TCL-Pesticide/PCBs(P/PCBs)	8081
Total Dissolved Solids	160.1	Freon	502.1
ICAP Metals	200.7	Volatile Organic Compounds	502.2
GFAA Metals	200.9	Volatile Organic Compounds MassSpec	524.2
Gas Generator Metals	245.1	TCL-VOC	8260b
TAL-Metals(23)	200.7 CLP	TCL-SVOC	8270c
Total Nitrogen(TKN)	351.3	Acid Extractable Fraction MassSpec	625/8270
Ammonia	350.3	Base Neutral Fraction(MS)	625/8270
Total Phosphorus	365.3	Residual Chlorine	330.5
Ortho Phosphorus	300.0a	Dissolved Oxygen	360.1
Anions(10)	300a&b	Temperature	
Turbidity	180.1	pH	150.1
Cyanide	335.2	Conductivity	120.1
Fecal Coliform	SM9222D	Hardness	200.7
Total Coliform	SM9222B	Sites Sampled	
Total Organic Carbon	415.2	Flow Rates	
Microwave Digestion	*	PM-10 Air Samplers	
Hotplate Digestion		TCLP	1613
Phenols	420.1	Metals extraction	1613
Sept Funnel Extraction BNAE		Metals fraction analytical	1613
Organic sample concentration		Semi-volatile extraction	1613
Pesticides	505/8081	Semi-Volatile Fraction	1613
Herbicides	515/8150	ZHE extraction	1613

Table 6.1.1.4 Analytical Parameters and Methods

6.1.2 Gas and Material Science Laboratory

The Gas and Material Science Laboratory Services / Gas and Material Analysis Laboratory (GMAL/GMSL) supports NASA as well as other Government agencies and aerospace contractors. This branch is divided into two sections. GMSL activities are primarily focused on providing a technical capability that is required to meet SSC's propulsion needs with emphasis added – to stand ready and to react quickly to customer demands site wide. Most operations in the test complex cannot proceed until lab results are received; consequently, delays in lab support are costly and can impact test schedules or other planned activities. The lab also provides investigative efforts necessary to understand and solve gas and material problems associated with rocket engine testing, plume analysis, and material compatibility issues by performing lab and field studies.

6.1.2.1 Gas Analysis

Gas analysis functions are an integral part of propulsion test activities. Determination of contaminants / impurities is routinely required for receiving inspection of gaseous and cryogenic commodities. Also, lab analysis is frequently required to verify purity requirements, assessing contamination from the transfer of propellants and pressurants, and gas system integrity following field maintenance activities. The lab is also frequently required to verify the cleanliness level (NVR and particulate analysis) of components / hardware used in contamination sensitive systems throughout the site. Most propulsion test activities cannot proceed until lab analysis is completed; consequently, lab services are performed on a scheduled and non scheduled basis.

Gas Analysis Capabilities:

- Selected and total impurities in propellants and pressurants
- Gas moisture measurements
- Total gaseous hydrocarbon content
- Condensable hydrocarbons
- CO and CO₂
- O₂ purity
- CFC's and iron determination in hydraulic fluids
- Particle size and counts
- Trace O₂
- Argon and nitrogen purity
- Non volatile residue analysis (gravimetric)
- Non volatile residue analysis (IR transmission)
- Non volatile residue analysis (IR reflectance)
- Density
- Moisture determination in liquids
- Gas standard certification
- Methane and neon determination
- Breathing and missile grade air analysis
- Acetylene determination in LOX
- Analysis of IR reactive gasses
- Preparation and analysis of swab and wipe samples
- Active oxygen lost
- Clean room certification

6.1.2.2 Material Analysis

Identifies unknown materials / contaminants, determines failure mode and root cause analysis on components and materials. Once the root cause is determined, recommendations are developed to prevent reoccurrence. The lab's familiarity with propulsion test hardware, and gas systems allows the staff to integrate propulsion related issues / problems with laboratory results to resolve a wide variety of technical problems.

Analysis expertise includes evaluation of hardware failures, process problems, evaluation of life cycle test failures, defect detection, contamination analysis, corrosion and environmental effects, and product design review. Failure analysis reports provide a clear picture of the root cause, and include recommendations to avoid future failures - from hardware design, through material selection and processing.

Material Analysis Capabilities:

- Fracture Evaluation
- Failure Mode Determination
- Fatigue
- Fractography
- Overload
- Ductile/Brittle Failures
- Chemical Attack
- Stress Corrosion Cracking
- Contamination and Corrosion Analysis
- Particle Analysis/Identification
- Filter Residue Analysis
- Process/Manufacturing Problem Analysis
- Root Cause Analysis
- FTIR Microscopy Identification of organic based contaminants
- Scanning Electron Microscopy – surface features and morphology
- Polarized light microscopy
- Elemental mapping of elements
- Research & development
- Material Selection/Processing/Design Recommendations

Major Equipment Included:

- Scanning Electron Microscopes (SEM) acquires a 3D image to reveal fractures, inclusions and to perform physical measurements. In addition, the SEM is used to establish evidence of stress and/or corrosion. This often allows for identification of the source, such as chemical reactions or mechanical wear. The SEMs are equipped with an energy-dispersive x-ray spectrometer, allowing for qualitative analysis. X-ray surface mapping can be performed to display the arrangement and distribution of elements and is useful to assess the phase composition of alloys or sample homogeneity.
- Fourier Transform Infrared (FTIR) spectrometers identify and quantify a chemical compound according to its molecular spectra. The FTIRs are used to identify NVR-inclusive hydrocarbon/non-hydrocarbon contaminants such as elastomers and softgoods.

INSTRUMENT	FUNCTION
Gas Chromatograph (4)	Helium and Hydrogen gas analysis
FTIR (2)	Nonvolatile residue (NVR) analysis
FTIR / ATR	Non metallic material identification
Hydrocarbon Analyzers (2)	Hydrocarbon as methane concentrations in gases
Moisture Analyzers (4)	Moisture concentrations in gases
CO/CO ₂ Analyzer (1 each)	CO/CO ₂ concentration in gases
Oxygen (O ₂) Analyzer (2)	Measures percent oxygen (O ₂) in Gases
Trace Oxygen (O ₂) Analyzer (1)	Impurities in N ₂ and He
Laminar Flowbench	Particulate analysis and identification
Radionuclide Analyzer	Field analysis requiring qualitative and quantitative analysis of materials
Scanning Electron Microscope (2)	Micro-contamination analysis
FTIR Microscope (1)	Organic contamination analysis

Table 6.1.2.2-1 GMSL's Major Analytical Instrumentation and Diagnostic Functions

Tasks	Tasks
THC	CO/CO ₂
Moisture	GC / Helium
Particulates (Gas @ Range)	GC / Hydrogen
Particulates (Fluids @ Range)	GC / Oxygen
O ₂ Purity	pH
Trace O ₂	Conductivity
Coulometric Titrations	Condensable Hydrocarbons
Fe Hydraulic Fluid	Acetylene Content
CFC's Hydraulic Fluid	Scientific Support
% H ₂ O ₂	H ₂ O ₂ Passivation
Ammonium	Failure Analysis
Hydrocarcon / NVR	Micro-contamination

Table 6.1.2.2-2 Gas and Material Laboratory Capabilities

6.2 Measurement Standards and Calibration Laboratory (MS&CL)

The MS&CL performs calibrations, test and repair services. These calibrations and measurements are all traceable to National or Intrinsic standards of measurement. Repair services vary from basic on mechanical instruments to component level on electrical instruments. The laboratory actively participates in the NASA Metrology and Calibration Working Group and maintains membership in the National Conference of Standards Laboratories (NCSL). Laboratory Capabilities are presented in Table 6.2.11-1.

6.2.1 Standards Laboratory

The Standards Laboratory transfers extremely accurate electrical and physical calibrations from reference standards to secondary transfer and working standards. These secondary standards are then used in measurements and other calibrations. Many standards laboratory measurements utilize statistical techniques designed to reduce measurement uncertainty. The accuracy and uncertainty requirements found in the standards laboratory result in many accuracy ratios that are less than 4:1. The laboratory participates in NASA Measurement Assurance Programs (MAPs) that help to ensure laboratory capabilities. These MAPs include Volt MAP, Resistance MAP, Extended Resistance MAP, Mass MAP, Gage Block MAP, Accelerometer MAP and Temperature MAP. In addition the laboratory utilizes the NASA Portable Josephson Array Voltage Standard to maintain DC voltage traceability. Highlights of the Standards Laboratory capabilities include:

- DC Voltage: 0 to 1000 volts
- AC Voltage: 0 to 1000 volts
- Resistance: 0.0001 Ohm to 100 Mohm
- Mass: 1 mg to 60 kg
- Pressure: 0.2 to 12,140 psig

6.2.2 Dimensional Laboratory

The Dimensional Laboratory performs calibrations and measurements on geometrical characteristics of instruments and components. The Laboratory serves the NASA metrology community actively as the pivot laboratory for the NASA Gage Block MAP. Laboratory Capabilities include:

- Lengths: 0 to 80 inches
- Roundness: 0 to 14 inches diameter
- Threads: 4 to 80 pitch
- Surface Plates: 0 to 1,000 sec
- Optical Angle: 0° to 360°
- Surface Roughness: 20 μin to 125 μin
- Hardness: accuracy of ± 1.0 unit of the Rockwell Standard

6.2.3 Electrical Calibration and Instrumentation Repair Laboratory

The Electrical Calibration Laboratory provides calibration and repair services for a wide variety of general measurement equipment. The laboratory is equipped with automated systems that provide automatic and semiautomatic calibrations. The following is a sample of laboratory capabilities:

- Multimeters: Volt (0 to 1000 v), Ohm (1 to 1 G Ω), Current (0 to 100 A)
- Oscilloscopes: 50 μ v/Div to 5 v/Div into 50 Ω , 50 μ v/Div to 200 v/Div into 1M Ω , 5 sec to 0.4 nsec
- Signal Generators: 0 to 18 GHz, 0 to -172 db
- Sound-Level: 20 Hz to 2.5 kHz
- Frequency Counter Time Base: $\pm 5 \times 10^{-12}$
- Watt-meters: 0 to 50 W, 10 to 1000 MHz
- Tachometers: 15 to 20000 rpm
- Photometers: 0.1 to 1000 foot-candles
- Radiation Survey Meters: less than 5,000 mR
- Phase Angle: 0 to 360°
- Combustible Gas Monitors: 0 to 100% LEL
- Oxygen Level Meters: 0 to 21.9% O₂

The instrumentation section of the laboratory performs modifications, rework, repairs and functional checks of all types of instrumentation, amplifiers and signal conditioners used for testing and data collection as well as other miscellaneous types of electronic equipment. The following types of instrumentation and equipment are a representative sample of overall capabilities:

- AC amplifiers and DC amplifiers (both manual and computer programmable), transducer amplifiers, signal conditioners, and filter modules.
- High intensity light sources, chart recorders, regulated and unregulated power supplies.

6.2.4 Pressure Laboratory

The Pressure Laboratory provides calibration and repair of pressure measuring and pressure generating equipment such as transducers, digital and analog gages, and dead weight testers. The laboratory provides in-place calibration services throughout SSC. Calibration services can be scheduled as to maintain the cleanliness level of instrumentation under test. Automated pressure calibrations are available to 60,000 psig. Some capabilities of the pressure laboratory are listed on the next page:

- Calibration using air and hydraulics to 60,000 psig
- Vacuum calibration down to 1 mm of mercury (mmHg)

6.2.5 Flow Laboratory

Calibration services are provided for liquid and gas flow measuring instruments. Direct air and nitrogen gas calibrations are available. Flow characteristics of other gases, such as hydrogen or helium, can be computed:

- Liquid flow from 0.01 to 300 gal/min
- Gas flow from 0 to 800 ft³/min
- Moisture analysis from 0.1 to 1,000 ppm

6.2.6 Mechanical Laboratory

Calibration is provided for various force measuring instruments. Capabilities include:

- Torque calibrations from 0 to 2,000 ft-lbs
- Force calibrations from 0 to 120,000 lbf

6.2.7 Wind Tunnel

Calibration of air velocity instruments and large airflow devices are performed in the Wind Tunnel's 3 ft. diameter test area. Capabilities range from 0 to 80 m/s.

6.2.8 Vibration Laboratory

The Vibration Laboratory calibrates accelerometers and other vibration measuring equipment.

6.2.9 Temperature Laboratory

The SSC Temperature Laboratory is an active participant in the NASA Temperature Measurement Assurance Program (TMAP). Participation includes the additional responsibilities of pivot laboratory. As pivot laboratory the SSC lab serves the NASA metrology community as the coordinator of all TMAP activities and as a metrology resource for all temperature measurement activities.

The Temperature Laboratory performs calibrations on all types of temperature and humidity sensing devices. Laboratory capabilities include:

- Temperature calibration from –180 to 500 °C.
- ITS90 fixed point calibrations at the Triple Point of Mercury, the Triple Point of Water, the Freezing Point of Tin and the Freezing Point of Zinc.
- Temperature and Humidity chamber: Relative Humidity from 15 to 95%.

6.2.10 Cleaning Laboratory

The Cleaning Laboratory performs cleaning and certification of instruments to NASA Standard 79-001 for LOX service. This certifies that the hydrocarbon content and particulate size and count are within the constraints of the standard.

6.2.11 Metrology Engineering

Metrology Engineering provides technical support concerning metrology and calibration problems. Specifically it provides:

- Support to the laboratories when non-routine and/or difficult measurements or calibrations occur. This involves assuring the proper equipment and techniques are used for each measurement. When such non-routine measurements are made, the metrology engineering staff will establish total uncertainty to assure proper accuracy in assignment to the test items.
- Support to the customer during and after calibration or measurements by acting as a liaison between the customer and the technicians who performed the calibration to ensure that all requirements are understood and provided. In the event post calibration problems occur the metrology engineering staff will provide support to the user in the evaluation of the problem.
- Conducts and acts as lead on all SSC MAPs.
- Serves as MS&CL technical resource by remaining current in the latest metrology and calibration theories, equipment, methodologies, research and standards. Serves the laboratory as member delegate to the NCSL. Participates and actively supports the NASA Metrology and Calibration Working Group.
- Metrology Engineering is also responsible for other laboratory functions such as reverse traceability, calibration interval assignment and adjustment, and laboratory point of contact for all auditors.
- Provides specific support as required for any special and/or unusual technical problems for the lab.

6.2.12 Fabrication and Development Laboratory

The Fabrication Laboratory offers electronic and mechanical fixture development. The laboratory offers a kind of one-stop shopping for its customers, adding an element of convenience to systems development.

- Staffing consists of technicians with a wide variety of expertise ranging from microprocessor development to undersea systems development, field support, and precision machining.
- Mechanical fabrication services are available for a wide assortment of project support, including mill and lathe work, welding and sheet metal. The lab possesses in-depth experience in working with aluminum, stainless steel, copper, brass, delrin, PVC, lexan, and many other metal and plastic material stocks.
- The laboratory provides in-house printed circuit board design and fabrication of boards up to 11 in. x 17 in. double sided.
- Electronic fabrication services are available for design and integration of electronic systems, ranging from design and layout to integration of off-the-shelf components into custom enclosures. A wide variety of test equipment is available including oscilloscopes, logic analyzers, signal generators, counters and power supplies.

Table 6.2.11-1 MS&CL Capabilities

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
DC VOLTAGE	0.1 V	± 1.1 ppm	Solid State Voltage Reference and Precision Divider
	1.0 V	± 0.5 ppm	Datron 4910 Solid State Voltage Reference
	1.018 V	± 0.5 ppm	Datron 4910 Solid State Voltage Reference
	10 V	± 0.5 ppm	Datron 4910 Solid State Voltage Reference
	100 V	± 1.1 ppm	Solid State Voltage Reference and Precision Divider
	1000 V	± 1.1 ppm	Solid State Voltage Reference and Precision Divider
AC VOLTAGE	2 mV to 0.6 V @10 Hz to 1 MHz	± 6 to 2900 ppm	Fluke 792A Thermal Transfer Standard
	1 V to 30 V @10 Hz to 1 MHz	± 18 to 108 ppm	Holt 11 Thermal Transfer Standard
	10 V to 1000 V @10 Hz to 100 kHz	± 17 to 110 ppm	Holt 11 Thermal Transfer Standard
RATIO, DC	1:1x10 ⁻⁷ to 1:1.1 to 1:1	± 0.1 ppm	Ratio Build-Up Terminal Resistance Boxes
RATIO, AC	1:001 to 1:1 @	± 0.5 ppm	ESI DT72A Ratio Transformer

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
	1 kHz		
RESISTANCE	0.0001 Ω	± 5.0 ppm	Standard Resistors, Standard Current Source and DVM
	0.001 Ω	± 5.0 ppm	Standard Resistors, Standard Current Source and DVM
	0.01 Ω	± 2.5 ppm	Standard Resistors, Standard Current Source and DVM
	0.1 Ω	± 2.5 ppm	Standard Resistors and Guildline Current Comparator
	1 Ω	± 1.0 ppm	Thomas 1 Ω Standard Resistor
	10 Ω	± 2.5 ppm	Standard Resistors and Guildline Current Comparator
	100 Ω	± 2.5 ppm	Standard Resistors and Guildline Current Comparator
	1 k Ω	± 2.5 ppm	Standard Resistors and ESI Resistance Bridge
	10 k Ω	± 1.0 ppm	ESI SR104 Standard Resistor
	100 k Ω	± 2.5 ppm	Standard Resistors and ESI Resistance Bridge
	1 M Ω	± 3.0 ppm	L&N 4050-B Standard Resistor
	10 and 100 M Ω	± 5.0 ppm	Standard Resistors and DMM
	> 100 M Ω	$\pm 0.05\%$ to 1.0%	Guildline TeraOhm Meter
DC CURRENT	20 A to 100 A	$\pm 0.05\%$	Valhalla 2575A Current Shunt
	2 A to 20 A	± 25 ppm	Fluke Y5020 Current Shunt
	1 μ A to 2 A	± 10 ppm	Standard Resistors and DVM
AC CURRENT	10 A to 100 A DC to 1 kHz	$\pm 0.1 \%$	Valhalla 2575A Current Shunt
	2 A to 20 A 1kHz to 10 kHz	± 25 ppm	Fluke Y5020 Current Shunt
	10 mA to 2 A 10 Hz to 5 kHz	± 50 ppm	Fluke A40 Current Shunts
CAPACITANCE	1 pF to 1.111 μ F	± 10 ppm @1 kHz	Andeen Hagerling 2500A

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
	100 pF	± 20 ppm @100 Hz \pm 10 ppm @1 kHz	GR 1404B Standard Capacitor
	1000 pF	± 10 ppm @100 Hz \pm 20 ppm @1 kHz	GR 1404A Standard Capacitor
INDUCTANCE	0.1 mH to 99,999 H	$\pm 0.12\%$ @100 Hz and 1 kHz	GR 1689M Digibridge
	100 μ H	$\pm 0.167\%$ @100 Hz \pm 0.152% @1 kHz	GR 1482-B Standard Inductor
	1 mH	$\pm 0.035\%$ @100 Hz \pm 0.038% @1 kHz	GR 1482-E Standard Inductor
	10 mH	$\pm 0.032\%$ @100 Hz \pm 0.032% @1 kHz	GR 1482-H Standard Inductor
	100 mH	$\pm 0.032\%$ @100 Hz \pm 0.033% @1 kHz	GR 1482-L Standard Inductor
	1 H	$\pm 0.030\%$ @100 Hz \pm 0.080% @1 kHz	GR 1482-P Standard Inductor
	10 H	$\pm 0.032\%$ @100 Hz \pm 0.032% @1 kHz	GR 1482-T Standard Inductor
RF ATTENUATION	0 to -120 db 10 MHz to 18 GHz	± 0.02 db	NIST certified attenuator and NIST traceable measurement receiver.
RF POWER	0 to 50 W 10 to 1000 MHz	$\pm 0.5\%$ of reading ± 0.1 Hz	NIST certified sensor, frequency counter and power signal source.
FREQUENCY TIME BASES	100 kHz, 1 MHz, 5 MHz & 10 MHz	Accuracy: $\pm 5 \times 10^{-12}$ Stability: $\pm 2 \times 10^{-12}$	Cesium Beam frequency standard representing a natural physical constant.
ANGULAR FREQUENCY (RPM)	15 to 20,000 rpm	$\pm 0.3\%$ range	Tachometer calibrator traceable to a natural physical constant.
PHASE ANGLE	0 to 360°	$\pm 0.01^\circ$	NIST traceable phase angle standard.
Dimensional LENGTH	0.05 to 20 inches 0.5 to 100 mm 0 to 80 inches (0 to 2.032 m)	± 1 μ in to ± 4 μ in ± 0.05 μ m to ± 0.06 μ m ± 50 μ in absolute or \pm 20 μ in when used with corrections	Gage Blocks and Mechanical Gage Block Comparator. Gage Blocks and Mechanical Gage Block Comparator. Gage blocks and a supermic/80 inch measuring machine.

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
INSIDE MEASUREMENT	0.25 to 14 inches	$\pm 10 \mu\text{in}$	Internal Super Micrometer
PITCH DIAMETER	4 to 80 pitch	$\pm 10 \mu\text{in}$	Thread Wires and a Super Micrometer
SHADOW AND PROFILE PROJECTION	0 to 14 inches	$\pm 0.0001 \text{ inch}$	Gage Blocks and an Optical Comparator
OPTICAL ANGLE	0° to 90° in 1 second steps 0° to 360° in 1° steps	$\pm 0.18 \text{ arc seconds}$ $\pm 0.14 \text{ arc seconds}$	Angle Blocks Indexing Table
FLATNESS	0.05 to 6 inches	$\pm 1 \mu\text{in}$	Interferometer
(SURFACE PLATES)	0.0 to 1000 sec	± 4 and ± 20 seconds	Federal Surface Plate Calibrator
COATING THICKNESS	6.3 microns to 1.75 mm	$\pm 5\%$	NIST Standard Reference Materials
SURFACE FINISH	20 μin to 125 μin	$\pm 2 \mu\text{in}$ to $\pm 6 \mu\text{in}$	Federal Surface Analyzer
HARDNESS	ROCKWELL B&C Scales	± 1.0 unit of the ROCKWELL Std.	Industrial ROCKWELL hardness standards and hardness comparator
ACOUSTICS Sound Pressure Level	114 db from 20 Hz to 2.5 kHz	$\pm 0.2 \text{ db}$	Microphone reciprocator traceable to a natural physical constant for frequency and to NIST for sound level.
TEMPERATURE	-50°C to 300°C 0.01° C (fixed) -38.8344° C (fixed) 231.928° C (fixed) 419.527° C (fixed)	$\pm 0.01^\circ \text{ C}$ $\pm 0.0005^\circ \text{ C}$ $\pm 0.0005^\circ \text{ C}$ $\pm 0.005^\circ \text{ C}$ $\pm 0.010^\circ \text{ C}$	Platinum Resistance Thermometer with Rosemount Oil Bath Triple Point of Water Cell Triple Point of Mercury Cell Freezing Point of Tin Cell Freezing point of Zinc Cell
PRESSURE	0.2 to 600 psia/psig	$\pm 50 \text{ ppm}$	Ruska 2465 Dead Weight Piston

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
	6 to 12,140 psig	± 100 ppm	Gage Ruska 2400HL Hydraulic Dead Weight Piston Gage
	30 to 60,000 psig	± 100 ppm	DH 53100 Hydraulic Dead Weight Piston Gage
VACUUM	0.001 to 1 Torr	From $\pm 2.53\%$ @ 0.001 Torr to $\pm 0.70\%$ @ 1 Torr	MKS 390HA Capacitance Vacuum Standard
MASS	1 mg to 60 kg	± 10 μ g to 100 mg	Mass Standards and Balances
FORCE	0 to 600 lbf	± 14.3 lbf	Dead Weight
	5000 lbf	± 0.59 lbf	Morehouse Proving Ring
	10,000 lbf	± 0.81 lbf	Morehouse Proving Ring
	60,000 lbf	± 6.4 lbf	Morehouse Proving Ring
	120,000 lbf	± 24 lbf	Morehouse Proving Ring
TORQUE	0.5 to 215 ozf-in	$\pm 0.2\%$ reading	Waters Torque Calibrator
	10 lbf-in to 2,000 lbf-ft	$\pm 0.1\%$ reading	AKO Torque Calibrators
Flow			
LIQUID	0.01 to 300 gals/min	$\pm 0.1\%$ reading	Cox 311 Volumetric Flow Calibrator
GAS	0 to 50,000 cm ³	$\pm 0.2\%$ reading	Sierra Cal Bench
	0 to 20 ft ³ /min	$\pm 0.35\%$ reading	Cubic Foot Bottle
	0 to 800 ft ³ /min	$\pm 0.58\%$ reading	Sonic Nozzles
WIND SPEED	0 to 1000 fpm	± 10 fpm	TSI Hot Wire Anemometer
	1000 to 15,748 fpm	$\pm 1\%$ of reading	Standard Pitot Static Tube

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
MOISTURE	0.1 to 1000 ppm	± 0.5 ppm	Standard Dew Point Hygrometer
GAS METER CALIBRATION			
Hydrogen & LEL Meters	0% H ₂ (0.0% LEL) 0.4% H ₂ (10% LEL) 1.0% H ₂ (25% LEL) 2.0% H ₂ (50% LEL)	$\pm 0.001\%$ (0.025% LEL) $\pm 1\%$ (0.1% LEL) $\pm 1\%$ (0.25% LEL) $\pm 1\%$ (0.5% LEL)	Certified Ultra-High Purity Helium Certified Hydrogen/Air Mixture Certified Hydrogen/Air Mixture Certified Hydrogen/Air Mixture
Oxygen Monitors	0% 10.4% 20.8%	$\pm 0.01\%$ O ₂ content $\pm 0.21\%$ O ₂ content Intrinsic Standard	Certified Ultra-High Purity Nitrogen Certified Helium/Air Mixture Ambient Air free of interference gases
Carbon Monoxide Monitors	10 ppm CO 20 ppm CO 1430 ppm CO	± 0.2 ppm CO ± 0.4 ppm CO ± 14.3 ppm CO	Certified Carbon Monoxide/Air Mixture Certified Carbon Monoxide/Air Mixture Certified Carbon Monoxide/Air Mixture
Carbon Dioxide Monitors	3% CO ₂	$\pm 0.06\%$ CO ₂	Certified Carbon Dioxide/Nitrogen Mixture
Sulfur Dioxide & Hydrogen Peroxide Meters	10 ppm SO ₂ or H ₂ O ₂	± 0.2 ppm SO ₂ or H ₂ O ₂	Certified Sulfur Dioxide/Nitrogen Mixture
HUMIDITY			
RELATIVE	15% to 95%	$\pm 1\%$ Relative Humidity	Standard Psychrometer System
ABSOLUTE	-100°F to 167°F	$\pm 0.36^\circ$ F	Standard Dew Point Hygrometer
OPTICAL RADIATION / PHOTOMETRY	0.1 to 1000 foot-candles	$\pm 2.5\%$	NIST traceable incandescent lamp and current source
VIBRATION	10 Hz to 10 kHz @ 10 g pk	10 to 50 Hz $\pm 2\%$ 50 Hz to 2 kHz $\pm 1\%$ 2.0 kHz to 10 kHz $\pm 2\%$	Bruel and Kjaer 8305 Standard Accelerometer
FLUID DENSITY/ SPECIFIC GRAVITY	0.001 to 2.0 g/cm ³	± 0.00001 g/cm ³	Mettler DMA58 Density Meter

PARAMETER	RANGE	BEST UNCERTAINTY	STANDARD
MAGNETICS, AXIAL & TRANSVERSE	311 to 10,000 gauss	± 3%	Standard Magnets
VOLUME, LIQUID	0.001 ft ³ to 1 ft ³	± 2.2 x 10 ⁻⁷ to ± 0.024 ft ³	Volume Computed with Density and Mass of Water
PULSE RISETIME	≤ 70 pSec	± 6pS	NIST traceable pulse generator.

Table 6.2.11-1 MS&CL Capabilities

7.0 Information Systems

The Information Technology Services (ITS) contractor provides data acquisition and control services for all SSC facilities and resident agencies. ITS provides the following categories of support:

- Applications Support and Software Development
- Data Systems and IT Operations
- Telecommunications
- IT Security Services
- Information Resources Management
- Process Engineering
- Planning & Scheduling Services
- Audio/Visual and Video Services

Support is provided to NASA and NASA contractors, Resident Agencies, universities and commercial entities under the direction of NASA points of contact for shared services and specific task orders. A variety of computing architectures are supported, including mainframe, client-server, web-based thin clients, and desktops.

The above list of support categories are described in the following paragraphs.

7.1 Applications Systems

Applications Support encompasses life-cycle support of hardware and software systems for business, scientific and engineering applications.

Business support focuses on maintenance of Financial and Institutional applications software, ranging in scope from web-based applications, desktop client-server, to mainframe applications.

The SSC Mainframe LPAR is located at Marshall Space Flight Center (MSFC) and supports the financial, procurement, shipping and receiving systems for NASA and its contractors. It also hosts several NASA Agency-wide applications for the NASA user community. The Stennis LPAR receives its system programming support from the NASA Data Center (NDC) at MSFC but local applications programming support is provided.

Institutional applications are increasingly developed to utilize the ubiquitous World Wide Web (WWW) browser software provided on every desktop computer. This approach allows familiar, standardized access to a wide range of critical functions, including financial reporting, administrative, and programmatic activities.

Scientific support is also provided for applications software. In addition, software engineering and systems integration/implementation/ administration are performed.

Areas of expertise include: satellite applications, systems analysis, data visualization/computer graphics/image processing, and satellite applications.

Direct support is provided to the Engineering & Science Directorate for engineering and business needs, such as data acquisition, web portal, process automation, information management, and data warehouse/mining capabilities. Integrating commercial off-the-shelf applications and database management systems such as Oracle and SQL Server to solve propulsion test data problems is a major component of this support.

7.2 Software Development

Software development is performed for applications to be run on desktop, web-based, client-server, GIS, mainframe, automated workflow processes. Software development practices follow the best-of-breed methodologies developed by the Software Engineering Institute for their Software Development Capability Maturity Model (SW-CMM).

Development and operational languages include: C, C++, COBOL, JAVA, FORTRAN, Visual Basic, VBA, LabView, HTML, and Assembly. COTS development environments include: Oracle, MatLab, PV-Wave, Arc/Info, X Motif, Open GL, Windows API, Embedded SQL, Power Builder, Natural, Informed, Windchill, and Ultimus. Scripting languages include: Perl, C shell, Bourne shell, Expect, Tcl/Tk, JCL, and REX. Web development tools include: Front page, ArcIMS, Dreamweaver, ASP, and Visual Interdev.

Problem domains addressed include: web-based e-business, financial, database, engineering/scientific, remote sensing/GIS, real-time, data acquisition, data visualization and modeling, data fusion/integration.

7.3 Data Systems and IT Operations

Data Systems and Operations support encompasses operation and administration of the Stennis Data Center, the SSC IT Security Program, NASA-owned telecommunications assets, and IT planning.

Application and web page hosting, pooled license management, production data processing and digitization, CD mastering services, high-end print capability, Tape/CD library management, backup, archival and restoration services are provided. Capability and services include:

- 24X7 operational capability
- secure 4 tier network environment
- redundant power systems
- high performance network connectivity
- Windows, Linux, HP-UX, Irix, Solaris computing environments

- ADATABASE, Oracle, SQL Server databases
- TCO, Capacity, consolidation and obsolescence planning
- Disaster recovery and COOP planning
- Systems administration
- Database administration
- Website registration and administration
- Performance tuning and monitoring

The Stennis Data Center (commonly referred to as SDC) has evolved from what was once primarily a financial and administrative computer facility into a full-function data center supporting e-business as well as unique Propulsion Test and Institutional IT requirements. Data Operations provides a wide range of computer systems that are critical for the Stennis Space Center community. The SDC hosts web-based and client server applications and remote Mainframe computer applications for the Stennis user community. Additionally, the SDC has extended data storage and archival capabilities beyond the walls of building 1110 through the implementation of the SDC Storage Area Network (SAN). The SDC SAN delivers 2GB/sec fibre channel connectivity to program and institutional customers across SSC.

7.4 Administrative Telecommunications Support

The ITS provides administrative support for critical NASA-owned telecommunications assets and data services. Administrative support is provided for:

- Data Center servers
- Non-ODIN desktops
- Coordination of WAN off-site circuits
- Pager services
- Video-teleconferencing facilities
- Billing reconciliation for ODIN, NISN, telephones
- Reimbursable billing reports development

7.5 IT Security Services

Information technology security is an integral part of all IT development and operations, ensuring ongoing access, availability, and integrity of critical systems and information assets. The ITS contract provides staffing and expertise to the NASA IT Security Manager for development, administration and execution of the IT Security Program at Stennis. While the NASA IT Security Program is coordinated at the Agency-level, it is administered locally at each Center, following guidance provided by NPR 2810.1. Coordination is also maintained with onsite Resident Agencies to ensure compatible and complementary programs. Capabilities and services include:

- IT Security plans and Contingency plans
- Intrusion detection scanning and analysis

- Incident response and investigations
- Risk analyses
- System Vulnerability assessment
- Critical infrastructure planning
- Continuity of operations planning
- Security notifications and bulletins
- Security awareness training

7.6 Information Resources Management

The ITS develops and administers systems to assist SSC users in the effective management of critical information. Categories of information resource management include:

- Documentation management systems
- Drawing management systems
- Image management systems
- Records management systems
- Knowledge management systems
- Forms development and automation

7.7 Process Engineering

Process engineering capabilities not only provide for effective operations and production, but also the continuing assurance of quality output and products. Services include:

- Process definition and analysis
- Design and re-engineering
- Workflow automation
- Configuration management
- Continuous quality improvement
- Certified ISO audits

7.8 Planning and Scheduling Services

Strategic and tactical IT planning support is provided through the ITS contract to the NASA/SSC Chief Information Officer and Institutional Division Chief. Programmatic and institutional requirements are mapped to existing IT assets and infrastructure. Alignment with NASA Agency, as well as relevant industry standards, is ensured. Annual and five year technology budget and technical planning are supported. Planning and scheduling services include:

- IT strategic and tactical planning

- Annual and five year equipment and technology plans
- Project planning, tracking, reporting,
- Cost, schedule, resource allocation, forecasting
- Scheduling tools

The Scheduling group delivers integrated, scalable project management solutions for the Engineering & Science and Information Systems Directorates. The Group is responsible for the coordination of workflow within or between work areas and units, the development and/or review of program schedules, work documents, and daily work area priorities.

7.9 Audio-Visual and Video Services

Audio-visual and video services are available to support all types of conferencing, multi-media and presentation requirements. Capabilities include:

- Conference room event support
- Conference room multimedia design and configuration
- ViTS reservations/facilitation
- Multimedia event setup and production
- Analog and digital video production in multiple formats
- Closed captioning support
- Test firings, documentaries, training, safety, special events

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8.0 FACILITY OPERATING SERVICES (FOS)

FOS, provided by an onsite contractor to NASA, supports NASA and the resident agencies at SSC. Areas of support, as related to the SSC propulsion-testing mission, include Facility and Operations Engineering Services, Facility Services, Institutional Services, and limited Technical Services. Additional information related to these select facility and operations support services is contained in the following sections.

8.1 Facility and Operations Engineering Services

The FOS Contractor provides engineering services in the planning, project development, design, construction, modification, repair, and maintenance of site facilities, systems, and equipment. Also, FOS Engineering assists with documentation, energy management, space utilization, spares provisioning, and certification of pressure vessels.

8.1.1 Engineering Services

This service provides the core engineering support such as design, specification development, drawings, construction management and evaluation of standards and requirements compliance. Engineering evaluations, studies, and reports are provided on a project as required. The FOS contractor is supplemented by subcontracting with A&E firms as required for specific engineering talent not available at SSC. Local manpower agencies also provide for supplemental engineering talent.

8.1.2 Documentation

Full documentation services are provided, including the monitoring of all project documentation and the writing and revising of Maintenance Instructions, SSC Standards, and Technical Procedures. The Computer Aided Design and Drafting (CADD) operators prepare engineering drawings on the modern CADD equipment, utilizing both Computer Vision and AutoCAD software systems. Central Engineering Files (CEF) maintains files on all historical and current engineering documentation. Copies of any documentation are readily available to requestors through CEF.

8.1.3 Energy Management and Space Utilization

The Energy Management and Space Utilization function provides specific information regarding energy costs, utilization, personnel headcount within buildings, and configuration changes to the buildings.

8.1.4 Spares Provisioning and Certification of Pressure Vessels

The Spares Provisioning program monitors the availability of spare components and parts used in the Test Complex area. Through this program, FOS Engineering ensures that spares are either available in the warehouse or procured when needed. Also for

the Test Complex, FOS Engineering provides American Society of Mechanical Engineers (ASME) certification of existing pressure vessels and assists in the procurement, design, and certification of new pressure vessels. The FOS contractor currently holds both the R and U stamps, thereby being able to do both repairs and manufacture pressure vessels in accordance with ASME codes.

8.1.5 Construction Services

The FOS engineers are responsible for the implementation of construction projects through subcontractors. In doing so, they provide surveillance of the construction to ensure contract compliance for NASA and the resident agencies. As the principle liaison between the construction contractor and the Government, they are responsible for all aspects of the construction contract, including coordination, progressive payments, labor compliance, submittal approval, safety, and the closeout of their projects.

8.1.6 Safety Services

FOS Safety Services provide for center-wide safety programs in the areas of system safety, construction safety, OSHA-required inspections, mishap investigations, safety awareness, safety information management, facilities safety, industrial safety, OSHA-required safety training, and field surveillance and monitoring.

8.2 Facilities Services

Facilities services include work processing, facilities support, system engineering and numerous shops and operations. These are described in further detail in the following sections.

8.2.1 Work Processing

The Work Processing group provides support to the following areas:

- Service Desk function for minor maintenance and service requests
- Facility temperature and humidity control and after hour facility support (24 hour a day support) through the Energy Management and Control System
- SRS/SWR receipt and processing

8.2.2 Facilities Support

Facilities Support is responsible for developing and maintaining Facilities Systems reports and analysis. This group provides administration of the Preventive Maintenance Program. They also provide support to the following areas:

- MAXIMO support functions includes trending and analysis of Preventive and Corrective Maintenance activities as well as NASA Facilities Maintenance data
- Management of various facility service subcontracts including
 - Pest Control and Herbicide
 - Refuse Pickup
 - Roofing
 - Painting
 - Carpeting
 - HVAC

8.2.3 Maintenance Engineering/PT&I

Maintenance engineers oversee the maintenance of facilities and associated equipment (including development and update of the Preventive Maintenance (PM) program), utility systems operation, and conduct annual facility inspections to ensure that needed maintenance is identified. Reliability centered maintenance engineering studies systems to determine proper maintenance resource allocation. System engineering provides system surveillance and technical assistance to shop craftsmen. Predictive testing services are provided through coordination with the PT&I Shop. PT&I technology is used to provide a means for early detection of equipment problems, which allows for scheduled repairs before equipment fails. As a result, unexpected downtime is reduced and there is a cost avoidance savings. The FOS contractor PT&I group uses the following technologies during PM's on equipment at SSC:

8.2.3.1 Infrared Thermography

Infrared scanning performed during PM's on distribution panels, motor control centers, LV switchgear, substations and 30 miles of high voltage lines in order to locate "Hot Spots". Other uses include new construction assessment of electrical installations and locating piping/roof leaks and insulation breakdown. Any difference in temperature from -20 to 1,500 C can be displayed in a variety of color bands.

8.2.3.2 Vibration Analysis

Vibration data collected during PM's of pumps, cooling towers and centrifugal chillers. Data is analyzed through frequency spectrums and trend charts and identifies mechanical problems such as shaft imbalance, misalignment, looseness, bearing defects, etc.

8.2.3.3 Electric Motor Testing

Electric motor test performed on large pump and centrifugal chiller motors. De-energized tests can identify faults in the power circuit, insulation, stator, rotor and air gap. Current Analysis includes rotor bar and eccentricity analysis, inrush/startup trending and spectrum analysis. Power analysis test indicate voltage and current imbalances, excessive harmonic distortion and stator faults.

8.2.3.4 Oil Analysis

Samples collected from pumps, chillers and elevators and data analyzed through trend and comparison charts indicating presence of oil contamination and wear.

8.2.3.5 Battery Testing

Tests performed on UPS systems and data analyzed through trend and comparison charts of battery impedance and strap resistance. These tests identify the bad cells in the battery bank so that individual cells can be replaced instead of replacing the entire battery bank.

8.2.3.5 Ultrasound Detection

Uses include electrical inspection of high voltage lines & substations, bearing & mechanical inspections and leak detection.

8.2.4 Carpentry/Paint Shop

The Carpentry Shop provides all carpentry services, from framing buildings to cabinetry work, including the following:

- Doors and door-closers
- Ceiling and floor tile work
- Scaffolding
- Roofing
- Masonry work
- Partitions
- Furniture repair and refinishing

The Paint Shop provides all types of maintenance painting, including decorative and protective painting to interior and exterior building surfaces and equipment.

8.2.5 Equipment Operations

Equipment Operations provides operators for mobile cranes, bulldozers, backhoes, forklifts, front-end loaders, dump trucks, derricks and road graders; and also performs equipment operator qualifications, rigging, and proof-testing.

A Mississippi state-certified sanitary landfill is maintained for daily disposal of non-hazardous wastes.

8.2.6 Equipment Maintenance

Equipment Maintenance personnel provide preventive and corrective maintenance (PM/CM) services for all types of gasoline- and diesel-powered machinery.

8.2.7 Equipment Systems

The Equipment Systems team performs PM/CM on a wide variety of electrical and mechanical equipment such as cranes, UPS, elevators, derricks, jib and monorail hoists, bridge cranes, emergency lighting, MCC, substation transformers, circuit breakers, fire alarm systems, the navigational lock and bridge, and cathodic protection.

8.2.8 Mechanical/Plumbing Shop

The Mechanical/Plumbing Shop personnel perform installation, modification, preventive/corrective maintenance, and operation on plumbing/piping systems (with lines and valves up to a 30 in. diameter) including:

- Sanitary sewage
- Potable water systems
- Elevated tanks
- Pressure tanks
- Natural gas system
- Cathodic protection system
- High Temperature Water Distribution system
- Chemical Waste Disposal systems

They also carry out general mechanical activities on pumps, motors, lifting devices, test stand blast doors and windows, overhead rolling doors, and a wide variety of other mechanical systems. This shop also provides support to the Equipment Systems Shop in corrective maintenance of the navigational lock and bridge.

8.2.9 Electric & High Voltage Shops

The Electric & High Voltage Shop employees perform maintenance, repair, installation, and modification to all electrical systems and equipment, from 28 VDC controls to the 13.8 kV high-voltage distribution system.

8.2.10 Heating, Ventilating, and Air-Conditioning & Refrigeration Shop

The Heating, Ventilating, and Air-Conditioning & Refrigeration (HVAC & R) Shop performs operations, preventive maintenance, corrective maintenance, minor modifications, installations and upgrades on Heating, Ventilation, Air-Conditioning and Refrigeration systems. Additionally, the HVAC & R Shop is supported with various subcontractors for the performance of PM/CM associated with chiller systems, boiler systems, chemical water treatment and Energy Management and Control System (EMCS) building automation / control systems.

The HVAC & R Shop performs the above work on a wide variety of mechanical equipment and systems such as chilled water cooling systems, hot water & steam heating systems, HVAC chemical water treatment systems, air distribution systems,

light commercial and residential systems, domestic refrigeration systems and direct digital control building automation systems.

8.2.11 Energy Management and Control System Office

The Energy Management and Control System Office (EMCS) provide centralized, 24-hr operation, control and monitoring of HVAC, sewer; potable water; natural gas, electrical high and low voltage and other related facility utility and special-purpose systems. The EMCS office also prepares energy reports/analyses, manages fuels, coordinates radio/communications and facility utility system outages and perform emergency operations center duties.

The EMCS operating environment is the Siemens Building Technology APOGEE Insight system software and central station hardware platform configuration. This system provides real time monitoring, command and control of every aspect associated with various buildings and facilities at SSC.

Approximately 75 buildings/facilities are connected to this system. The EMCS APOGEE Insight building/facility automation system is currently comprised of approximately 30,000 field points at the floor level network. These points are connected to approximately 230 field stand-alone microprocessors at the building level network, communicating over 8 peer to peer networked data trunks routed to a main and back-up server at the management level network central station. The operating system man-to-machine interface is established at the management level network, and is currently comprised of 3 Insight color graphic operator workstations. Additionally, this management level network is configured to communicate with the SSC Ethernet and is available to all authorized computer workstations and supports operational visibility of the EMCS APOGEE technology as a site wide building automation information tool. Furthermore, the man-to-machine interface is available at the field sensor and field microprocessor level. This floor and building level network access allows field technicians to interface and use the system as a tool in the field using a computer laptop.

8.2.12 Custodial Services

Responsible for interior cleaning (mopping, sweeping, trash collection, carpet cleaning, windows, dusting) of FOS assigned facilities.

8.2.13 Roads and Grounds

Roads and Grounds personnel maintain paved and unpaved roads, improved lawns and landscaping, unpaved land, parking areas, and surface drainage systems.

8.3 Institutional Support Services

The FOS contractor provides institutional support services, and NASA and resident agencies administrative support.

8.3.1 Logistics Services

Logistic Services provides shipping/receiving, warehousing and storage, inventory management, equipment and disposal management, transportation management of GSA vehicles, warranty services, and Park-n-Fly operations for travelers to New Orleans airport. In addition, there are seven bench stock cribs staged strategically throughout SSC for use by the craftsmen in the Test Complex and near facility shops.

8.3.2 Institutional Services

The FOS contractor provides central cafeteria services for an a-la-carte breakfast and a full-service lunch menu five days a week; provides a site-maintenance satellite cafeteria, a mobile food service, and on-site catering services. Daily taxi-fleet operation, Visitors Center Tour Bus operation, special-request chauffeur support, airport vehicle dispatch operation, and GSA vehicle administration are provided. The movement of furniture, equipment and personnel is provided through a drayage crew. Continuous 24-hour/day fire protection is provided. The fire department conducts building, structure, and automatic system inspections; participates in facility design reviews; issues flame permits; provides standby coverage for operations as requested/required; operates an ambulance service for SSC with certified Emergency Medical Technicians (EMT) for medical emergencies. A medical clinic is located at SSC to provide emergency, therapeutic, and preventative medical treatment to employees. The clinic also provides health exams, pre-placement, certification, surveillance, fitness for work, termination, health maintenance, and special purpose examinations. The Wellness/Fitness Center provides state of the art fitness equipment, personal assistance, and counseling to assist members in meeting their personal health and fitness goals. Educational promotions, out reach programs, competitions, and health fairs are provided to develop fitness and support health awareness. Industrial Hygiene services provided by the FOS contractor cover a wide range of activities for health including asbestos air monitoring, indoor air quality investigations, asbestos inspections, R.A.P.I.D. Testing for Anthrax, and respiratory protection fit-testing. The FOS contractor maintains and operates SSC facility post office in conjunction with the U. S. Postal Service for the processing of official mail; provides delivery/pickup to buildings each day; and hand-delivers registered/certified mail. The U. S. Postal Service operates a Post Office at SSC to handle personal mail and postage.

8.3.3 Information Services

8.3.3.1 Visitors Center

The FOS contractor operates the SSC visitor center, StenniSphere. They conduct daily and special VIP tours and provide space-related programs. Conference support is available with audiovisual assistance in five NASA conference rooms and the Rouchon House as well as support to SSC off-site conferences and workshops. They also support NASA Public Affairs' outreach efforts by providing escort for visiting news media, news releases, newsletters and other printed materials.

8.3.3.2 Education Services

Education Services are provided by the FOS contractor to include a broad range of programs and initiatives to meet the needs of students and educators aimed at improving America's schools and supporting NASA's education goals. Programs and initiatives include, but are not limited to educator workshops and presentations to students and educators.

8.3.3.3 Multimedia Services

The Stennis Space Center MultiMedia department, Building 1105, provides NASA, resident agencies, and contractors a myriad of graphic, printing, photography, and other creative service/support capabilities. The veteran group develops poster, brochure, flyer, and other 2-dimensional graphic designs; 3-dimension static and motion graphics; digital and traditional photography, including passport or portrait photography; photo printing services; technical writing, editing, and proof reading; high speed reproduction/copying/scanning; custom matte and frame production; web site design, including motion graphics and Flash animation, and site maintenance; electronic presentation development, from simple PowerPoint to complex sound and video-incorporated designs; fabrication, and a host of other graphics-related capabilities.

8.3.4 Procurement

This function is performed by two specialized Branches, Purchasing and Contracts & Legal. Purchasing is responsible for obtaining supplies and services in support of 26,000 line items of inventory and the three prime NASA contractors. A sophisticated software system enhances the ability to transact over 18,000 orders annually and provides real-time interface with Finance, and Shipping and Receiving. Over the years, the vendor listing of qualified suppliers has grown to over 3,000, including the use of GSA.

The second Branch, Contracts and Legal, is responsible for those subcontracts of a more complex nature, such as those requiring a source evaluation. This typically includes service, cost reimbursement, and requirement-type subcontracts. In addition, the Legal Counsel is responsible for developing procurement policy in accordance with

Federal Acquisition Regulations (FAR), NASA Procurement Directives, and handling legal issues that arise as an adjunct of the procurement system.

The procurement system is kept current and is approved by the regional Defense Contract Management Agency (DCMA). Without sacrificing price or delivery, Small and Small Disadvantaged Businesses are awarded approximately 65% and 15% of the dollar value of procurements, respectively, which enhances the stature of the system with local business and gives them confidence in our commitment to the local economy.

8.3.5 Drayage and Labor

Drayage support provides labor for the pick-up and delivery of furniture, equipment and items that can be moved with a dolly. Entire office relocations are performed with this group along with general support to organizations.

8.4 Technical Services

Technical Services include a Fluid Component Processing Facility (FCPF), Weld/Fabrication and Machine Shops, Component Support, Test Operations, Construction Management, and Marine Operations.

8.4.1 Fluid Component Processing Facility

The FCPF services all pressure and cryogenic components and utilizes an environmentally controlled clean room. This facility provides for the service, repair, cleaning, testing, and certification of mechanical components, systems, and parts in support of propulsion test activities. Hydrostatic testing can be performed up to 30,000 psi and pneumatic testing up to 15,000 psi. Cryogenic testing of components, up to 30 in. in diameter, can be performed down to - 320 °F using LN₂. Assembly of components is performed inside a level 10K clean room.

8.4.2 Weld/Fabrication Shop

The Weld/Fabrication Shop provides gas welding or brazing and arc welding in accordance with ASME and American Welding Society (AWS) standards. Welders are certified to weld a wide range of metals (carbon steel, aluminum, and stainless steel), employing Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW), stick welding, and brazing processes. The shop can shear, roll, and press-form steel up to ¾ in. thick. Also, the shop is certified to fabricate and repair ASME-coded pressure vessels. The shop's capabilities consist of fabrication of sheet metal, structural members, panels, template plates, high pressure and cryogenic piping, vessels, and all types of experimental prototype components, assemblies and systems.

8.4.3 Machine Shop

The Machine Shop provides services for fabrication, repair, and modifications involving plastics, nylon, Teflon, and metals. The shop is capable of fabricating complete assemblies from blueprints or sketches to the finished product. The shop Machine Shop operates lathes, milling machines, boring mills, shapers, drill presses, and grinders. The shop is also equipped with one Hurco, three-dimensional, computer-controlled machine having a 52-inch capacity along the “x” axis, 30-inch capacity along the “y” axis, and 24-inch capacity along the “z” axis. The shop has heat-treating capability for items up to 2 ft x 2 ft x 3 ft, and a vertical mill provides milling tolerance to a 120-inch diameter and precision machining of parts to tolerances of ± 0.001 inches.

8.4.4 Component Support

Component Support provides professional engineering services in direct support of the test complex. These engineers provide expertise in ASME and NASA standards. These engineers provide the following services:

- a. Prepare and maintain current procedures for maintenance repair cleaning and testing of HP and cryogenic system components.
- b. Provide LOX, GOX, H₂ and H₂O₂ expertise for materials compatibility.
- c. Perform system/component failure analysis for HP and cryogenic system failures.
- d. Provide improved component/system designs and/or modifications resulting from failure analysis.
- e. Provide spares provisioning for systems of responsibility.
- f. Provide technical assistance to shops/associate contractors as required.
- g. Provide for configuration management and control coordination with Engineering Services Division.
- h. Provide expertise for developing specifications and RFQ packages for the procurement of HP and cryogenic components.

8.4.5 Test Operations

Test Operations consists of project management and design engineers who provide rapid response engineering support to the Test Complex. This group prepares designs, construction specifications, and cost estimates for facility modifications within the Test Complex and other propulsion testing programs. Using the Area Engineer Concept, the group identifies requirements, initiates necessary work, and follows the implementation of such work to completion. This group also oversees the Pressure Vessel Recertification Program for SSC including ASME Coded Pressure System designs and

repairs. Test Operations Engineers oversee the maintenance of facilities, systems, and equipment, and conduct annual facility inspections to ensure that needed maintenance is identified.

8.4.6 Construction Management

Construction Management coordinates implementation of repair maintenance and special projects within the Test Complex using shop forces. Construction Management provides direction, planning, estimating, and oversight of all work including construction reviews and technical recommendations. All work is closely coordinated with other contractors on site.

8.4.7 Marine Operations

Marine Operations is responsible for operating a 1200 hp, push-type tugboat within the SSC canal system and the Mississippi/Louisiana coastal and inland waterways, to barge fuel in support of SSC engine testing. They also handle the operation of SSC's navigational lock and bascule bridge.

8.4.8 Quality Services

The FOS contractor provides Quality Assurance Engineering oversight for the primary fabrication support groups at SSC. Also provided are Quality Technicians who conduct process verification and certification acceptance testing.

8.5 Nondestructive Test and Evaluation Laboratory [9]

The NDTE Laboratory furnishes support in all aspects of nondestructive testing and evaluation of structural and material integrity investigations. These include material inspections for surface and internal flaws, identification and quantification of gas leakage from pressurized gas systems and the verification of “fitness-for-service” of facility systems. All SSC pressure vessels and barges are periodically inspected and re-certified as mandated by applicable codes and standards. Periodically, the NDTE Laboratory is requested to conduct nondestructive testing and evaluation of SSME components.

This laboratory is capable of performing inspections and diagnostics both in the field and in the laboratory. To accomplish its many tasks, the laboratory has an extensive inventory of test equipment and certified technicians for performing a variety of NDTE methods. Some of the laboratory's inspection and/or diagnostic capabilities include radiography, ultrasonic, liquid penetrant, and visual examination including boroscopy, magnetic particle, mass spectrometer leak detection and eddy-current testing.

Radiography as well the other NDTE methods in use at SSC has been performed on various SSME components, including the main LOX inlet manifold seam welds, high pressure gas storage vessels and pressure piping, cryogenic storage vessels and cryogenic transfer lines. When required, mobile film-processing facilities are available

to support field radiographic operations. Equipment in service at SSC NDTE Laboratory includes but is not limited to the following as tabulated in Table 8.5-1.

NDTE Major Equipment Listing	
Equipment	Function
Boroscopic inspection system	Inspects interior of vessels, piping, etc.
Leak detector (portable)	Helium mass-spectrometer leak detection system
Ultrasonic Flaw Detection	Detects flaws in material and welds
Pancake GM Detector	Radioactive Leakwipe Analysis
Liquid penetrant testing system	Testing of metals for surface defects
Magnetic particle testing coils	Testing of ferromagnetic metals (circular)
Magnetic particle testing yokes	Testing of ferromagnetic metals (longitudinal)
New Age Versitron hardness tester	Hardness testing of materials (Rockwell C)
Radiographic darkroom trailer	Film processing
Radiographic exposure device (cobalt-60)	Examines metals up to 9 in. thick
Radiographic exposure device (iridium 192)	Examines metals up to 3.5 in. thick
Magnaflux ED-800	Eddy Current Testing
Temperature testing probe	Tests temperatures of materials
Thiokol Equotip hardness tester	Hardness testing of materials (portable)
Ultrasonic thickness gauges	Measures material thickness
X-ray system [Andrex (160 kV)]	X-ray of materials up to 1 in. thick (portable)
X-ray system [inner view (60 kV)]	Detailed inspection of electronic components
Liquid penetrant system (Zyglo)	Surface inspection of small parts

Table 8.5-1 NDTE Laboratory Equipment

8.5.1 Radiographic Inspection (RT)

A radiograph is basically a two-dimensional picture of the intensity distribution of some form of radiation projected from a source that has passed through a material object that partially attenuates the intensity of radiation. Voids, changes in thickness, or regions of different composition will attenuate the radiation by different amounts, thus producing a projected shadow of themselves. Using x-rays and gamma rays for the penetrating radiation, the radiographic information is captured on film or fluorescent

screens. In real-time systems, a television camera collects the image on a fluorescent screen and the image is subsequently digitized for enhancement analysis and storage.

8.5.2 Ultrasonic Testing

Ultrasonic testing is a nondestructive method wherein beams of ultra high frequency sound waves are introduced into a test object to detect and locate surface and internal discontinuities. Detection, location, and evaluation of discontinuities are possible as the velocity of sound through a given material is nearly constant. This makes distance measurements possible. The amplitude of the reflected pulse is nearly proportional to the size of the reflector. Material thickness measurement is accomplished by measuring the time required for the pulse to travel through the material, reflect off the opposite surface, and return.

8.5.3 Liquid Penetrant Testing

Liquid penetrant inspection is a process for locating flaws that are open to the surface in solid, essentially nonporous materials. The test article in the area of interest is first coated with the penetrant solution. After a certain dwell time, the excess penetrant is removed. Any flaws open to the surface will retain a small portion of the penetrant. A developer is then applied to the test surface. Due to capillary action, the remaining dye will be drawn to the surface of the object being inspected. The results are then interpreted. Except for visual inspection, liquid penetrant is perhaps the most commonly used nondestructive test for examination of nonmagnetic parts.

8.5.4 Magnetic Particle Testing

Nondestructive magnetic particle testing is used to detect surface or near-surface discontinuities in magnetic materials. The method is based on the principle that the magnetic lines of force in a ferromagnetic material will be distorted by the change in material continuity. If a discontinuity exists in a magnetized material, surface or otherwise, the magnetic force lines will be distorted. When fine magnetic particles are spread over the area of discontinuity, they will accumulate at the discontinuity. This accumulation of particles will be visible under proper lighting conditions.

8.5.5 Leak Testing

Mass Spectrometer Leak Detection (MSLD) is a method utilized to ensure pressure system or vacuum integrity. This is an extremely sensitive test method in which helium is used as a tracer gas. In pressure systems, the test object is pressurized using a gas mixture including a minimum of 10% helium within the mixture. The test object is then scanned with the MSLD unit and any leakage noted. When testing a vacuum system, the test article is evacuated with the MSLD unit sampling the vacuum annulus. Helium is then introduced as a blanket around the article being tested and any leakage into the test object will be observed.

8.5.6 Eddy-Current Testing (ET)

Eddy-current testing is a method used to locate surface or subsurface flaws in electrically conductive materials and to evaluate material characteristics; for example, hardness, heat-treat, other metallurgical conditions. The test article is brought into a time-varying electromagnetic field that induces electrical current into the test article. The force field of the electric current resembles eddies that are seen in the turbulent waters of a flowing stream. The amount of electrical current passing through a test article is determined by the electrical conductivity of the test article, as well as the frequency and amplitude of the magnetic field. Eddy-current testing is used to detect surface and subsurface flaws, irregularities in material structure, and variation in chemical composition in metallurgy.

8.5.7 Visual Inspection

Visual inspection is a nondestructive method of evaluating materials for the detection of discontinuities that are open to the surface; for example, cracks, seams, laps, cold sheets, laminations and porosity. With the advent of Digital Photography, an extensive database of photos documenting various system conditions is being assembled. Remote visual inspection is possible utilizing a boroscope or similar equipment. Visual inspection is the initial method used in evaluating the condition of cryogenic storage and pressure vessels, pipelines and valves, liquid propellant transfer barges, and test engines. The three methods of visual inspection by the NDTE Laboratory include direct, remote, and translucent.

8.5.8 Hardness Testing

Hardness testing is a mechanical test for evaluating the properties of metals and certain other materials. Hardness testing is used at SSC to determine if purchased and/or contractor construction materials meet the design specifications. Such materials can be piping, beams, vessels, and plating. Hardness testing is also used in the analysis of cause when determining a system failure, if such testing is applicable. The major hardness tests used are indentation, scratches, cutting, abrasion, and erosion.

8.5.9 Bubble Leak Testing

Leak detection is a direct pressure-testing method used to locate leaks in a pressurized component by the application of a solution that will form bubbles as leaking gas passes through the component. Leak detection testing at SSC is used to detect leaks in the site-wide piping systems, pressure vessels, vacuum jacketed lines, storage vessels, and the propellant-transfer barges.

9.0 OUTSOURCING DESKTOP INITIATIVE FOR NASA (ODIN)

The ODIN Contractor provides computer desktop, data communications, telecommunications, administrative radio, onsite television network circuits, infrastructure enhancements, catalog of IT products and services, and other outsourcing support services to all Stennis agencies.

9.1 Office Automation

The Office Automation Software that supports the test facility is referred to as Stennis Desktop Services (SDS). SDS is built around the Microsoft Office product Office Suite and is implemented as the NASA SSC standard for office automation. These services allow for e-mail, scheduling, calendar management, and access to the Internet. Included in the SDS are standard PC or MAC applications to assist the individual. These applications include Microsoft Word, Microsoft Excel, Microsoft PowerPoint and Microsoft Project. All the above services operate in a Microsoft Windows or MAC environment. Linux is also an available OS and has similar office support.

Platforms include PCs, MACs, and Unix systems.

Also included, but not limited to, is tablet PCs, Blackberries, virtual team meeting services, file services, web services, CAP Support, an array of network printers, catalog for additional IT capabilities and services, secure dial in and web access, and IP Management.

9.2 Telecommunications

ODIN provides state of the art telecommunications services to SSC, including:

- a. Telephone (digital & analog) and Voice Messaging
- b. Switched and dedicated data circuits
- c. LAN network connectivity, off-site access
- d. Trunked land-mobile radio service with very limited telephone connectivity
- e. Site-wide CATV video distribution with satellite down-links from major information services (CNN, Headline News, etc)
- f. Video Teleconferencing
- g. Cell phones
- h. Virtual Meeting Services

Telecommunications services, other than radio, are provided through a mix of copper and fiber cable plant. Most new services are routed on a combination of single-mode and multi-mode fiber plant supporting bandwidths from 1 mbs to 2.1 gbs.

9.2.1 Telephone System

The telephone system provides digital & analog, dedicated & switched voice and data service as well as low speed dial up data connectivity up to 56 kbs. The system also supports Primary Rate Interface ISDN (Integrated Services Digital Network). The system currently supports approximately 6000 user ports with the capability of supporting 20,000 ports.

Special high-speed dedicated data circuits are provided at speeds ranging from 56 kbs to 45 mbs. Engineering, design, and implementation of all levels of data services are supported as well as operational maintenance. Current reliability measurements of the telephone system are 99.999% reliability.

9.2.2 LAN

ODIN also provides and supports a switched LAN environment of approximately 2500 computers belonging to NASA, NASA contractors, and resident agencies. Engineering, design, and implementation of all network requirements are done within the Telecommunications group. Norton Antivirus is included with each LAN Seat. Protocols that are currently approved for use on the SSC LANs are:

- a. TCP/IP
- b. UDP/IP
- c. AppleTalk

9.2.3 Circuits and Wiring

ODIN is also responsible for the engineering, design, implementation, and maintenance of all premise distribution systems throughout SSC. Currently, category 6 unshielded twisted pair, capable of 1000 Mbps transfer rates, is being used as the standard for wiring to the end user environment. The distribution system is further supported by intelligent networking hubs capable of providing a minimum of switched 10 Mbps to the desktop, remote monitoring to the node level, and problem resolution via internal diagnostic capabilities. These switches are routed back to the Telecommunications complex over the site wide fiber distribution system utilizing the ATM (Asynchronous Transfer Mode) standard LANE 2.0 at 155 Mbps and 622 Mbps and 1 and 10 Gigabit Ethernet backbones.

Off-site WAN access is provided through a series of firewall and/or routers to the NASA Integrated Systems Network (NISN). The NISN provides such services as Internet access as well as primary network support for Space Shuttle Main Engine (SSME) test data. ODIN is not responsible for working these off site requirements; however, they are responsible for on-site coordination.

9.2.4 Network Operations Center

ODIN also uses a Network Monitoring Center (NMC), which proactively monitors the health of SSC network systems and gathers appropriate usage statistics for analysis. This center performs all first and second level maintenance on all communications systems. The maintenance crew is backed by third level vendor maintenance contracts and support as required. All maintenance activities, including preventive and corrective maintenance, are coordinated to maximize system availability and minimize user impacts. Extended coverage, 6:00am - 6:00pm is provided for Telecommunication systems.

9.2.5 Wireless Communications

ODIN also operates the SSC Motorola Trunked UHF radio system supporting approximately 500 fixed, mobile, and portable radios in approximately 40 active radio networks. Off site telephone connectivity is provided to some radio networks (e.g. Fire & Security, Disaster Recovery, Emergency Operations Center, etc.), to coordinate activities with off site emergency service providers.

ODIN also maintains other UHF, VHF, and HF wireless radio networks.

Pagers are not provided under the ODIN contract but are provided by NASA and administered through TTSC support services.

9.2.6 Video Network

Current news and weather information and educational television programming are provided through the SSC Video Network. This system uses standard CATV and studio components to provide 17 channels of video service to approximately 85 SSC locations. Programming consists of fixed information services (e.g. CNN, The Weather Channel, National Weather Service, Lightning Detection and Warning), received from off site. Other services (commercial television broadcasts), are provided on a demand basis. In addition, the system is configured to allow remote origination of video programming (e.g. engine test firings, Public Affairs programming etc.) from end user locations back to the telecommunications complex for processing and retransmission across SSC. Satellite downlink capabilities are provided within the ODIN contract also.

Low Bandwidth Video (LBV) is also offered for as an inexpensive means for periodic video conferencing requirements. Portable units are available and can be located anywhere on SSC that contains premise distribution wiring. The LBV is not provided under the ODIN contract but is provided by NASA.

9.2.7 Desktop Computers

Another valuable component of ODIN is the provision and maintenance of ADPE (Automated Data Processing Equipment). The ADPE unit provides desktop to desktop repair of PCs, servers, workstations, printers and various other peripheral equipment as well as installation and maintenance of all NASA standard software suites supporting office automation. Currently the group supports approximately 6700 pieces of equipment throughout SSC which includes institutional and demand agencies, i.e. NASA, NASA Contractors, SSME, etc.

9.2.8 Help Desk

ODIN is also responsible for the help desk for IT support. Troubles or status information on requests can be obtained by calling the on-site help desk. Responses to troubles are a function of the service level being procured for a user's IT (phone, desktop, etc). ODIN also has Outreach support with telephone, URL, and e-mail access.

10.0 OTHER

10.1 Cray Supercomputer

NAVOCEANO's Major Shared Resource Center (MSRC) for High Powered Computing is available to SSC for modeling and analysis. The center includes 4 Cray SV-1-EX computers and offers aggregate capabilities in excess of 25 trillion operations per second.

The MSRC's supercomputers can meet the large-volume computational demands of advanced propulsion development.

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APPENDIX A

REFERENCE DOCUMENTS AND DRAWINGS

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REFERENCE DOCUMENTS

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- [16] S-IC Stage Test Program, Mississippi Test Facility, Bay St. Louis, MS, Test & Quality Evaluation Office, October 29, 1970.
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REFERENCE DRAWINGS

- (1) 11BGK-P001—Stennis CTF Project—Piping and Instrument Diagram, LO Unloading, Storage, and Transfer.
- (2) 11BGK-P002—Stennis CTF Project—Piping and Instrument Diagram, LO, LP, and HP Run Tanks, Sheet 1 of 2.
- (3) 11BGK-P002—Stennis CTF Project—Piping and Instrument Diagram, LO, LP, and HP Run Tanks, Sheet 2 of 2.
- (4) 11BGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LO Turbopump Assembly Test Cell, Sheet 1 of 3.
- (5) 11BGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LO Turbopump Assembly Test Cell, Sheet 2 of 3.
- (6) 11BGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LO Turbopump Assembly Test Cell, Sheet 3 of 3.
- (7) 11CDK-P001—Hydrogen Liquid—HPGF Hydrogen Shelter Piping, Schematic, Sheet 1 of 3.
- (8) 11CDK-P001—Hydrogen Liquid—HPGF Hydrogen Shelter, Air Products Storage System, Utility Flow Diagram, Sheet 2 of 3.
- (9) 11CDK-P001—Hydrogen Liquid—HPGF Hydrogen Shelter, Utility Flow Diagram, Sheet 3 of 3.
- (10) 11CGD-P001—Hydrogen Gaseous—A-1 Pressure-Reducing Area Piping Schematic, Sheet 1 of 1.
- (11) 11CGD-P002—Hydrogen Gaseous—S-II A-1 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (12) 11CGD-P003—Hydrogen Liquid & Gas—S-II Test Complex LH2 Barge Dock, Test Stand and Barge Flare Stack Piping Schematic, Sheet 1 of 1.
- (13) 11CGD-P004—Hydrogen Liquid—S-II A-1 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (14) 11CGF-P001—Hydrogen Gaseous—A-2 Test Stand, Pressure-Reducing Area Piping Schematic, Sheet 1 of 1.
- (15) 11CGF-P001—Hydrogen Gaseous—A-2 Test Stand, Pressure-Reducing Area Piping Schematic.

- (16) 11CGF-P002—Hydrogen Gaseous—S-II A-2 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (17) 11CGF-P003—Hydrogen Liquid—S-II A-2 Test Stand, LH2 Dock and Flare Stack Piping Schematic, Sheet 1 of 1.
- (18) 11CGK-P001—Stennis CTF Project—Piping and Instrument Diagram, LH2 Trailer Unloading, Storage, and Transfer, Sheet 1 of 2.
- (19) 11CGK-P001—Stennis CTF Project—Piping and Instrument Diagram, LH2 Trailer Unloading, Storage, and Transfer, Sheet 2 of 2.
- (20) 11CGK-P002—Stennis CTF Project—Piping and Instrument Diagram, LH2 LP and HP Run Tanks, Sheet 1 of 2.
- (21) 11CGK-P002—Stennis CTF Project—Piping and Instrument Diagram, LH2 LP and HP Run Tanks, Sheet 2 of 2.
- (22) 11CGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LH2 Turbopump Assembly Test Cell, Sheet 1 of 3.
- (23) 11CGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LH2 Turbopump Assembly Test Cell, Sheet 2 of 3.
- (24) 11CGK-P003—Stennis CTF Project—Piping and Instrument Diagram, LH2 Turbopump Assembly Test Cell, Sheet 3 of 3.
- (25) 11CGK-P004—Stennis CTF Project—Piping and Instrument Diagram, HP and UHP GH2 Storage, Sheet 1 of 1.
- (26) 11CGK-P006—Stennis CTF Project—Piping and Instrument Diagram Flare Stacks, Sheet 1 of 1.
- (27) 11CG0-P001—Hydrogen—S-II Test Complex, Hydrogen Gas Battery Area Piping Schematic, Sheet 1.
- (28) 11FDK-P001—Nitrogen System—HPGF Compressor Building, Nitrogen Pump Area Piping Schematic, Sheet 1 of 4.
- (29) 11FDK-P001—Nitrogen System—HPGF Compressor Building, Nitrogen Pump Area Piping Schematic, Sheet 2 of 4.
- (30) 11FDK-P001—Nitrogen System—HPGF Compressor Building, Nitrogen Pump Area Piping Schematic, Sheet 3 of 4.

- (31) 11FDK-P001—Nitrogen System—HPGF Compressor Building, Nitrogen Pump Area Piping Schematic, Sheet 4 of 4.
- (32) 11FGD-P001—Nitrogen—S-II A-1 Test Stand, Pressure-Reducing Area Piping Schematic, Sheet 1 of 1.
- (33) 11FGD-P002—Nitrogen—S-II A-1 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (34) 11FGF-P001—Nitrogen—S-II A-2 Test Stand, Pressure-Reducing Area Piping Schematic, Sheet 1 of 1.
- (35) 11FGF-P003—Nitrogen—S-II A-2 Test Stand, Main Supply, Sheet 1 of 1.
- (36) 11FGK-P001—Stennis CTF Project—Piping and Instrument Diagram, LN2 Trailer and HP Pump Vaporization, Sheet 1.
- (37) 11FGK-P001—Stennis CTF Project—Piping and Instrument Diagram, HP and UHP GN2 Storage.
- (38) 11FGK-P002—Stennis CTF Project—Piping and Instrument Diagram, GN2 Distribution System, Sheet 1, Sheet 2.
- (39) 11FG0-P001 (Rev. 6)—Nitrogen—Complex A, Inert Gas Battery Area Piping Schematic, Sheet 1 of 1.
- (40) 11GDK-P001 (Rev. 8)—Helium Gaseous—HPGF Compressor Loading and Storage Flow Diagram, Sheet 1 of 5.
- (41) 11GDK-P001—Helium Gaseous—HPGF Compressor Building, Purification, Sampling, and Supply, Sheet 5 of 5.
- (42) 11GGD-P001—Helium—S-II A-1 Test Stand, Inert Gas Pressure-Reducing Area Piping Schematic, Sheet 1 of 1.
- (43) 11GGD-P002—Helium—S-II A-1 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (44) 11GGF-P001—Helium—S-II A-2 Test Stand, Inert Gas Pressure-Reducing Piping Schematic, Sheet 1 of 1.
- (45) 11GG0-P001—Helium—Test Complex "A," Inert Gas Battery Area Piping Schematic, Sheet 1 of 1.
- (46) 11HDK-P001—High Pressure Air System—High Pressure Gas Facility Compressor Building Piping Schematic, Sheet 1 of 1.

- (47) 11HG0-P001—High Pressure Air—S-II Test Complex, Inert Gas Battery Area Piping Schematic, Sheet 1 of 1.
- (48) 11HGD-P001—High Pressure Air—S-II A-1 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (49) 11HGF-P001—High Pressure Air—S-II A-2 Test Stand, Inert Gas Pressure-Reducing Area Piping Schematic.
- (50) 11HGF-P002—High Pressure Air—S-II A-2 Test Stand, Main Supply Piping Schematic, Sheet 1 of 1.
- (51) 12B00-E001—SSC Electrical Distribution System—13.9-kV Single Line Diagram.
- (52) 31B00-K001—LOX Barges 1-6 Block Diagram—Advanced Schematic, Sheet 1.
- (53) 31B00-P001—Marine Equipment LOX Barge No. 1—LOX Piping Schematic (Typical) P/L Issued.
- (54) 31C00-P001—Marine Equipment LH2 Barge No. 1—Hydrogen Piping Schematic (Typical).
- (55) *Deleted*
- (56) 110GK-K006—Stennis CTF Project—Single Line Diagram.
- (57) 110GK-R004—Stennis CTF Project—Test Stand Sections, 4 Sheets.
- (58) 200GK-A308—Stennis CTF Project—Test Cell/SCB Foundation Plan Sections, 1 Sheet.
- (59) 460GK-H011—Stennis CTF Project—Site Plan.
- (60) *Deleted*
- (61) 11CGD-P003, P004—Modification to A-1 Test Stand—Liquid Hydrogen System Flow Diagram.
- (62) 11CGD-P003, 11FGD-P003—Modification to A-1 Test Stand—Liquid Hydrogen System Plan.
- (63) 11FG0-P001, 11FGF-P001—S-II Test Complex, Test Stand A-1—High-Pressure Nitrogen Flow Diagram.

- (64) 11FGD-P001, P003—S-II Test Complex, Test Stand A-1—High-Pressure Nitrogen Flow Diagram.
- (65) 11FGD-P002, P004—S-II Test Complex, Test Stand A-1—High-Pressure Nitrogen Flow Diagram.
- (66) 11GG0, P001—S-II Test Complex, Test Stand A-1—High-Pressure Helium System Flow Diagram.
- (67) 11GGD-P001, 11CGD-P002—S-II Test Complex, Test Stand A-1—High-Pressure Helium System Flow Diagram.
- (68) 11CG0-P001, 11CGF-P001—S-II Test Complex, Test Stand A-1—High-Pressure Hydrogen System Flow Diagram.
- (69) 11CGD-P001, 11CGD-P002—S-II Test Complex, Test Stand A-1—High-Pressure Hydrogen System Flow Diagram.
- (70) 11HG0-P001, 11CGF-P001—S-II Test Complex, Test Stand A-1—High-Pressure Air System Flow Diagram.
- (71) 11HGD-P001, 11HGD-P002—S-II Test Complex, Test Stand A-1—High-Pressure Air System Flow Diagram.
- (72) 11BGD-P001—S-II Test Complex, Test Stand A-1—Liquid Oxygen System Flow Diagram.
- (73) 11CGD-P003, 11CGD-P004—S-II Test Complex, Test Stand A-1—Liquid Hydrogen System Flow Diagram.
- (74) 11FG0-P001—S-II Test Complex, Test Stands A-1 and A-2—High-Pressure Nitrogen Flow Diagram.
- (75) 11FGF-P001—S-II Test Complex, Test Stand A-2—High-Pressure Nitrogen Flow Diagram.
- (76) 11CG0-P001—S-II Test Complex, Test Stands A-1 and A-2—High-Pressure Helium System Flow Diagram.
- (77) 11GGF-P001—S-II Test Complex, Test Stand A-2—High-Pressure Helium System Flow Diagram.
- (78) 11GG0-P001—S-II Test Complex, Test Stands A-1 and A-2—High-Pressure Hydrogen System Flow Diagram.

- (79) 11CGF-P001—S-II Test Complex, Test Stand A-2—High-Pressure Hydrogen System Flow Diagram.
- (80) 11HG0-P001—S-II Test Complex, Test Stands A-1 and A-2—High-Pressure Air System Flow Diagram.
- (81) 11HGF-P001—S-II Test Complex, Test Stand A-2—High-Pressure Air System Flow Diagram.
- (82) 11CGF-P001—S-II Test Complex, Test Stand A-2—Liquid Hydrogen System Flow Diagram.
- (83) 11CGF-P003—S-II Test Complex, Test Stands A-1 and A-2—Flare System Flow Diagram.
- (84) *Deleted*
- (85) 200GF-A019—S-II Test Complex, Test Stand A-2—Test Stand General Arrangement.
- (86) 11HB0-P001, 11FH0-P002, 11BHF-P001—S-IC Test Complex, Test Position B-2—High-Pressure Nitrogen System Flow Diagram.
- (87) *Cancelled*
- (88) *Cancelled*
- (89) 11FHD-P001—S-IC Test Complex, Test Position B-1—Overall Flow Diagram—HP Gas Systems—Nitrogen.
- (90) 11FHD-P001—S-IC Test Complex, Test Position B-1—Overall Flow Diagram—HP Gas Systems—Nitrogen System.
- (91) 11HHD-P001—S-IC Test Complex, Test Position B-1—Overall Flow Diagram—HP Gas Systems—HP Air System.
- (92) 11GHD-P001—S-IC Test Complex, Test Position B-1—Overall Flow Diagrams—HP Gas Systems—Helium.
- (93) 11BHD-P001—S-IC Test Complex, Test Position B-1—Overall Flow Diagrams Cryogenic Systems—Liquid Oxygen.
- (94) *Cancelled*
- (95) 200HD-A001—S-IC Test Complex, Test Position B-1, Test Stand General Arrangement.

- (96) MTF-SSE-G108—Modifications of Test Facilities for Space Shuttle Engine Testing—Test Stand A-2 General Notes.
- (97) MTF-SSE-S14—Modifications of Test Facilities for Space Shuttle Engine Testing Thrust Measuring System—General Arrangement Test Stand A-1.
- (98) MTF-SSE-S117—Modifications of Test Facilities for Space Shuttle Engine Testing Thrust Measurement System—General Arrangement Test Stand A-2.
- (99) 11CGF-P001—Modifications for Orbiter Propulsion System Test Facilities, Phase II—General Notes.
- (100) EMI FUB P0100—S-II Test Complex, Test Stand A-2—Liquid Hydrogen System Flow Diagram.
- (101) XDY90101 Figure A—Restoration of HPGF Existing Facility Site Plan, Building 3304 and 3305.
- (102) EMI H9A0D00020—High Heat Flux Rig Site Plan.

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

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ACRONYMS

—A—B—

AC	Alternating Current
A/D	Alternating to Direct Current
ADPE	Automated Data Processing Equipment
ALS	Advanced Launch System
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASRM	Advanced Solid Rocket Motor
ASTP	Advanced Space Transportation Program
A-TCC	"A" Test Control Center
ATM	Asynchronous Transfer Mode
AWS	American Welding Society
B-TCC	"B" Test Control Center

—C—

CA	Customer Agreement
CADD	Computer Aided Design and Drafting
CATV	Community Access Television
CBC	Common Booster Core
CCTV	Closed Circuit Television
CD	Compact Disk
CEF	Central Engineering File
CFD	Computational Fluid Dynamics
CLP	Contract Laboratory Program
C of F	Construction of Facilities
CTF	Component Test Facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CWA	Clean Water Act
CAA	Clean Air Act

—D—

DACS	Data Acquisition and Control System
DAS	Data Acquisition System
DC	Direct Current
DI	Deionized
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DVOM	Digital Voltage Ohm Meter

—E—

E&S	Engineering and Science
EEB	Electrical Equipment Building
EELV	Evolved Expendable Launch Vehicle
EPA	Environmental Protection Agency
EMA	Electro Mechanical Actuators
EMCS	Energy Management and Control System
EMT	Emergency Medical Technicians

—F—

FAR	Federal Acquisition Regulations
FCPF	Fluid Component Processing Facility
FFT	Fast Fourier Transform
FOS	Facility Operating Services
FMS	Flow Measurement System
FTIR	Fourier Transform Infrared

—G—

GH ₂	Gaseous Hydrogen
GHe	Gaseous Helium
GC	Gas Chromatograph
GMAL	Gas and Material Analysis Laboratory
GN ₂	Gaseous Nitrogen
GOX	Gaseous Oxygen
GMSL	Gas and Material Science Laboratory
GPM	Gallons per Minute
GSA	General Services Administration
GTAW	Gas Tungsten Arc Welding

—H—

HeSS	Helium Spin Start
HF	High Frequency
HHFF	High Heat Flux Facility
H ₂ O	Water
H ₂ O ₂	Hydrogen Peroxide
HMI	Human Machine Interface
HP	High-Pressure (3,000 psi to 8,000 psi)
HPA	High-Pressure Air
HPGF	High-Pressure Gas Facility
HPIW	High-Pressure Industrial Water
HSDAS	High Speed Data Acquisition System
HTDP	Hybrid Technology Demonstration Program
HVAC	Heating, Ventilating, and Air Conditioning

—I—

I/O	Input/Output
IRIG	Time standard accurate to 1 ms
ISDN	Integrated Services Digital Network
IT	Information Technology
ITS	Information Technology Services

—J—K—L—

JP	Jet Propellant
LAN	Local Area Network
LH ₂	Liquid Hydrogen
LN ₂	Liquid Nitrogen
LOX	Liquid Oxygen
LM	Liquid Methane
LP	Low Pressure
LSDAS	Low Speed Data Acquisition System
LBV	Low Bandwidth Video

—M—

MAC	Apple Macintosh Computer
MAP	Measurement Assurance Programs
MAWP	Maximum Allowable Working Pressure
MCC	Motor Control Center
MDWP	Maximum Design Working Pressure
MFP	Master Facility Panel
MP	Medium Pressure (1,000 psi to 3,000 psi)
MPTA	Main Propulsion Test Article
MSCL	Measurement Standards and Calibration Laboratory
MSFC	Marshall Space Flight Center
MSLD	Mass Spectrometer Leak Detection
MSRC	Major Shared Resource Center

—N—

NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
NCSL	National Conference of Standards Laboratories
NDC	NASA Data Center
NDTE	Nondestructive Testing and Evaluation
NISN	NASA Integrated Systems Network
NIST	National Institute of Standards and Technology
NLS	National Launch System
NMC	Network Monitoring Center

NVR	Nonvolatile Residue
NPDES	National Polluting Discharge Elimination Systems
NPDWR	National Primary Drinking Water Regulations

—O—P—

ODIN	Outsourcing Desktop Initiative for NASA
OI	Operator Interface
PC	Personal Computer
PCV	Pressure Control Valve
PLC	Programmable Logic Controller
PM	Preventive Maintenance
PM/CM	Preventive and/or Corrective Maintenance
PRA	Pressure Reducing Area
PRD	Project Requirements Document
PTA	Propulsion Test Article
PT&I	Predictive Testing and Inspection

—Q—R—

RLV	Reusable Launch Vehicle
ROM	Read-Only Memory
RP	Rocket Propellant
RTD	Resistance Temperature Detector
RCRA	Resource Conservation and Recovery Act

—S—

SCB	Signal-Conditioning Building
SCFM	Standard Cubic Foot per Minute
SDC	Stennis Data Center
SDS	Stennis Desktop Services
SEM	Scanning Electron Microscope
S&MA	Safety and Mission Assurance
SMAW	Shielded Metal Arc Welding
SPS	Samples per Second
SR&QA	Safety, Reliability, and Quality Assurance
SSC	John C. Stennis Space Center
SSME	Space Shuttle Main Engine
STE	Special Test Equipment
STS	Space Transportation System
SVHS	Super VHS
SDWA	Safe Drinking Water Act

—T—

TASS	Test Article Support Structure
T&E	Test and Evaluation
TCC	Test Control Center
TCP/IP	Telecommunication Control Program/Internet Protocol
TEA/TEB	Triethyl-Aluminum/Triethyl-Borane
TMAP	Temperature Measurement Assurance Program
TMS	Thrust Measurement System
TOB	Test Operations Building
TOC	Test Operations Contract
TTS	Thrust Takeout Structure

—U—

UDP/IP	User Datagram Protocol/Internet Protocol
UHP	Ultra High Pressure
UHF	Ultra High Frequency
UPS	Uninterruptible Power Supply

—V—W—

VHF	Very High Frequency
ViTS	Video Teleconferencing System
VJ	Vacuum Jacketed
VP	Valve Pit
WWW	World Wide Web

ABBREVIATIONS

°C	degree Celsius	mm	millimeter
°F	degree Fahrenheit	mmHg	1 mm of mercury
°R	degree Rankin	Mohm	megaohm
μ	micron (micrometer)	ms	millisecond
μin	microinch	MVA	megavoltampere
A	ampere	N ₂	nitrogen
atm	atmosphere	Ox	Oxygen
CH ₄	methane	ppm	parts per million
CO	carbon monoxide	psi	pounds per square
CO ₂	carbon dioxide		inch
ft	feet	psia	pounds per square
ft/sec	feet per second		inch atmosphere
ft ²	square feet	psig	pounds per square
ft ³	cubic feet		inch gauge
ft-lb	foot-pound	rpm	revolutions per minute
ft ³ /min	cubic feet per min	s, sec	second
gal	gallon	scf	standard cubic feet
gal/min	gallons per minute	scfm	standard cubic feet
gpm	gallons per minute		per minute
GHz	gigahertz	STD	standard
GM	gaseous methane	V	volt
H ₂	hydrogen	VAC	volts alternating
He	helium		current
hp	horsepower	VDC	volts direct current
Hg	mercury		
hr	hour		
Hz	hertz		
in.	inch		
kHz	kilohertz		
ksps	kilo samples per second		
kV	kilovolt		
kVA	kilovoltampere		
kW	kilowatt		
lb	pound		
lbf	pounds force		
lb/sec	pounds per second		
lbm/s	pounds mass per second		
lbm	pounds mass		
lb/hr	pounds per hour		
M	million		
M-lb	million pound		
M-gal	million gallon		
mi	mile		
min	minute		

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TEST FACILITIES CAPABILITY HANDBOOK

Volume II

MARSHALL SPACE FLIGHT CENTER

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1.0 MSFC INTRODUCTION

The George C. Marshall Space Flight Center (MSFC) in Huntsville, Alabama, is one of NASA's largest and most diversified installations. The Marshall Center has been a key contributor to numerous significant NASA programs during the Agency's 45-plus-year history -- from the 1961 flight of the first U.S. astronaut into space, to the Apollo missions exploring the Moon, to development and operation of America's Space Shuttle fleet, and construction of and scientific discovery aboard the International Space Station.

Marshall has the mission assignment to lead the Agency in space transportation systems development and microgravity research and optics manufacturing technology. MSFC provides leadership in the areas of management and implementation of research, technology maturation, design, development, and integration of space transportation and propulsion systems, including Space Shuttle propulsion element improvements, reusable launch vehicles, vehicles for orbital transfer and deep space missions, and qualification verification of new expendable launch vehicles.

As NASA's Center of Excellence for Space Propulsion, MSFC leads the development, implementation, and advocacy of advanced Earth-to-orbit and in-space propulsion systems and technologies. With specific NASA expertise in Microgravity Research, MSFC develops, integrates, and operates microgravity payloads and experiments, and supports the Johnson Space Center (JSC) on developing the International Space Station facilities; and conducts and manages microgravity research. MSFC is responsible for management of the Microgravity Research Space Product Development Programs, Second Generation Reusable Launch Vehicle Program, Advanced Space Transportation Program (ASTP) (comprising Space Transfer and Launch Technology Program and In Space Propulsion Program), Gravity Probe B Program, and manages the operation of the MSFC developed Chandra X-Ray Observatory.

1.1 History

The Marshall Space Flight Center was activated on July 1, 1960, with the transfer of buildings, land, space projects, property, and personnel from the U.S. Army Missile Agency. Dr. Wernher von Braun became the Center's first director.

The Marshall Center's first major program was development of the Saturn rockets, the largest of which boosted man to the Moon in 1969. Saturns also lifted Skylab and the Apollo spacecraft into Earth orbit for the historic linkup with the Russian-Soyuz spacecraft in 1975.

The Marshall Center has managed many other space projects successfully since its creation in 1960, including Pegasus (1965), three unmanned satellites to detect micrometeoroids; the Lunar Roving Vehicle (1971) for transporting astronauts on the lunar surface; Skylab (1973); the United States' first crewed orbiting space station; the

three High Energy Astronomy Observatories (1977, 1978, and 1979) to study stars and star-like objects; and the Hubble Space Telescope (1990), an optical observatory that is returning unprecedented views of the universe. A new era in space flight began on April 12, 1981, when Marshall-developed propulsion systems unleashed almost six-million pounds of thrust to launch America's first Space Shuttle.

The legacy of testing achievement at NASA Marshall includes the Saturn rockets that boosted humans to the Moon and the powerful Space Shuttle Main Engines. Marshall Space Flight Center testing "firsts" include:

- * First to test the Space Shuttle Main Engine using a lap top personal computer
- * First to test the Space Shuttle Main Engine at 30 percent rated thrust
- * First full-scale cryostructural test of a loaded Space Shuttle hydrogen tank
- * First test of the Apollo Saturn SIC Stage, F1 engine
- * First large thrust Russian rocket engine tested by the U.S. Government

More than 400 acres of land dedicated to testing are divided into three basic areas - the East, West and North Test Areas. The East Test Area is used primarily for engine component and subsystems testing. Complete systems are tested in the West Test Area. Aerodynamic research and aero/fluid dynamics testing are conducted in the North Test Area.



North Test Area



West Test Area



East Test Area

2.0 MSFC Propulsion Test Facilities

2.1 Introduction

NASA Marshall has more than 40 facilities capable of all types of rocket and space transportation technology testing - from small components to full-up engine systems. Marshall has tremendous engineering expertise, including supreme capability to research, conceive, evaluate, mature, analyze, design, develop, test and validate technologies for space transportation systems.

The new Component Development Area supports development of valves and other small components needed for 2nd Generation RLVs, while the nearby Advanced Engine Test Facility is one of only a few test stands in the world that can accommodate large, liquid-fuel rocket engines. The test facilities have extensive core capability in facility design and test article integration.

The engineers and technicians who support test facilities at Marshall have more than one thousand years of combined experience in testing. They offer a variety of experience and expertise in hazardous testing to provide customers the data needed to evaluate aerospace technologies and hardware. NASA Marshall has one of the few government test groups in the United States with responsibility for the overall performance of the test program from conception to completion.

2.2 Rocket Propulsion Testing

NASA Marshall's rich legacy of rocket propulsion testing began four decades ago as Dr. Wernher von Braun led the charge to develop the rockets that boosted humans to the Moon. Marshall performs experimental research and development testing of propulsion systems, subsystems and components and provides independent evaluation of the test results.

2.2.1 Combustion Research Facility



Combustion Research Facility

The Combustion Research Facility, also labeled Test Facility 115, is a multipurpose, multi-position facility capable of testing small or subscale rocket engine systems, medium pressure combustion devices and cryogenic tanks.

The facility's compact size makes it ideal for testing subscale components. It features both cold flow and hot fire positions. Optics and laser diagnostic systems are available for plume analysis. The Combustion Research Facility is located in NASA Marshall's East Test Area.

2.2.1.1 Liquid Hydrogen/Methane

Liquid Hydrogen/Methane is available at the facility. The storage capability is defined in the following table.

Propellant (liquid)	Volume (gallons)	Pressure (psig)
Hydrogen/Methane	2,200	1,500
Hydrogen/Methane	500	3,000
Methane/Rocket Propellant	20	3,000

2.2.1.2 Liquid Oxygen

Liquid oxygen is available from a 500 gallon tank at a pressure of 3,000 psig. Storage capability is 2,500 gallons.

2.2.1.3 Gaseous Oxygen

Gaseous Oxygen is stored at the facility in a 236 ft³ tube trailer at 2,400 psig.

2.2.1.4 Gaseous Hydrogen

Gaseous Hydrogen is stored at the facility in a 157 ft³ tube trailer at 3,800 psig. There is also a storage capacity of 490 ft³ at 4,000 psig.

2.2.1.5 Gaseous Nitrogen

Nitrogen is provided to the test facility through a 3-inch facility line at a pressure of 4,200 psig.

2.2.1.6 Gaseous Helium

Helium is stored at the facility in 238 ft³ tube trailers at a pressure of 4,500 psig.

2.2.1.7 Demineralized Water

Demineralized water is stored in a 500 gallon tank at 3,000 psig.

2.2.1.8 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.2.1.9 Hydraulic System

The hydraulic system has a flow rate of 10 gpm at 3,000 psig.

2.2.1.10 Instrumentation

The Combustion Research Facility can provide 500 low-speed digital data acquisition channels at 100 SPS. Also available are 15 (expandable to 180) high-speed digital channels at 250,000 SPS. The facility is equipped with high speed and infrared cameras and control systems with video monitoring.

2.2.2 Component Test Facility



Component Test Facility

The Component Test Facility, also known as Test Stand 116 (Building 4540) is an open structural steel construction incorporating a cantilevered section for mounting test items. There is no support structure within 22 feet from the centerline of the cantilevered tower framework. The structure is designed for 30K vertical thrust at cantilevered centerline. There is a five-ton bridge crane on the top (50-ft) level. A 20-ft

by 20-ft by 3-ft deep heavy reinforced concrete pad with embedded anchorage system is symmetrically aligned below the cantilevered centerline. It is designed for 60K horizontal thrust 10 ft above the pit floor.

This facility provides a unique capability providing acoustically clean environment and instrumentation for studies of dynamic pressures generated by noise sources. 90 degree, 75 meter expanded black-top area around the test stand provides this acoustically clean environment. It can readily be adapted for checkout tests of rocket engines, cryogenic valves, etc. Isolated location and direction of firing would accommodate exotic propellant tests.

148 acoustic measuring stations are strategically spaced on 10-degree intervals covering 180 degrees on a 250-ft radius hardstand area with its center being the cantilevered center. Acoustic instrumentation is ducted to the Control Building 4541.

Over the years, the test stand has evolved into a diversified component test stand for many different test programs which require high pressure and/or cryogenic propellants. The facility consists of an open steel test stand structure, a mechanical prep shop, an electrical control center, and two locations for signal conditioning equipment.

Instrumentation goes underground to the Instrumentation Center at Building 4583. The electrical control instrumentation is ducted underground to Control Building 4541, which is explosion proof with observation windows and a 2000 ft² working space.

The building contains power supplies, intercom, video, and areas warning equipment, cable terminals, control consoles, and signal condition equipment.

The Component Test Facility, also called Test Facility 116, is equipped to test high-pressure rocket engine system components, turbopumps, valves, cryogenic propellant system components, and combustion devices. The facility is designed to supply large-volume and high-pressure liquid and gas for testing. The multi-position test stand can run multiple tests simultaneously, saving time and propellant. It also can be used for environmental simulation tests. The Component Test Facility is located in NASA Marshall's East Test Area.

There are four positions within the Component Test Facility. The Turbine Blade Position can provide LOX, H₂, RP-1, and CH₄ to test articles. The Acoustic Model Position can withstand 30,000 lbf and can provide LOX, H₂, and RP-1 to test articles. The Preburner Position can withstand 50,000 lbf and can provide LOX, H₂, and CH₄ test articles. The fourth position is the 60,000 lbf Position, which has been upgraded from 40,000 lbf, and can provide LOX, H₂, RP-1, and CH₄ to test articles.

2.2.2.1 Liquid Oxygen

There is a 3,000 gallon tank that stores Liquid Oxygen at 5,250 psig. Storage at 28,000 gallons and 14,000 gallons is also available.

2.2.2.2 Liquid Hydrogen

There is a 2,200 gallons tank for storing Liquid Hydrogen at 6,000 psig. There is also a 2,000 gallon tank with a pressure of 8,500 psig

2.2.2.3 RP-1/High Pressure Water

Two 3,000 gallon tanks are available for storing RP-1 and/or high pressure water at 5,000 psig and 2,700 psig, respectively.

2.2.2.4 Gaseous Hydrogen

Gaseous Hydrogen can be stored in a vessel that is 600 ft³ at 10,000 psig. It can also be stored in a 1,250 ft³ vessel at 15,000 psig. Gaseous Hydrogen is provided to the facility through a 1.5-inch facility line at 4,400 psig.

2.2.2.5 Gaseous Nitrogen

Gaseous Nitrogen can be stored in a vessel that is 700 ft³ at 8,000 psig. It can also be stored in a 1,250 ft³ vessel at 10,000 psig. Gaseous Nitrogen is provided to the facility through a 3-inch facility line at 4,200 psig.

2.2.2.6 Gaseous Helium

Gaseous Helium is provided to the facility through a 1.5-inch facility line at 4,200 psig.

2.2.2.7 Missile-grade Air

Missile-grade is provided to the facility through a 1.5-inch facility line at 3,500 psig

2.2.2.8 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.2.2.9 Hydraulic System

The hydraulic system has a flow rate of 50 gpm at 3,000 psig.

2.2.2.10 Control/Instrumentation

The facility is equipped with a programmable logic controller with 600 outputs to remote valves. 1,000 low-speed digital data acquisition channels are available at 100 SPS. 78 (expandable to 180) high-speed digital channels are available at 250,000 SPS. It also has 288 analog tape channels. High speed and infrared cameras and control systems with video monitoring are available at the facility.

2.2.3 Hybrid & Engine Components Test Facility



Hybrid & Engine Components Test Facility

The Hybrid & Engine Components Test Facility is a multi-purpose, five-position test stand designed for hazardous testing of liquid hydrogen, liquid oxygen, methane, and solid and hybrid propulsion components and subsystems. Solid rocket motors, LOX or LH₂ turbopumps, turbomachinery components and thrust chamber assemblies have all been tested at this facility.

The bearing tester drive, used to test turbomachinery bearings and seals, is a 500 horsepower diesel engine with a variable-speed transmission to 40,000 rpm for liquid oxygen and a pressurant (gaseous nitrogen) with an electrohydraulic valve controller for liquid hydrogen.

All tests are controlled from the Control and Service Center in Building 4561, located approximately 500 feet southeast of the test stand. All instrumentation measurements are routed to the Data Acquisition Center in Building 4583. The Hybrid & Engine Components Test Facility, also called Test Facility 500, is located in NASA Marshall's East Test Area.

The facility has several positions available for testing:

- * 24-inch liquid oxygen hybrid/solid motor position
- * 11-inch liquid oxygen hybrid motor position
- * Liquid oxygen bearing test position
- * Liquid hydrogen bearing test position
- * Liquid hydrogen/liquid oxygen component test position

2.2.3.1 Liquid Oxygen

There is a 3,000 gallon tank that stores Liquid Oxygen at 2,000 psig. Storage is available in an elevated 23,000 gallon tank at 80 psig. Storage is also available in a 28,000 psig tank at 50 psig.

2.2.3.2 Liquid Hydrogen

A 5,000 gallon tank stores Liquid Hydrogen at 2,000 psig. A 100,000 gallon tank stores Liquid Hydrogen at 75 psig. Storage is available in an elevated 36,000 gallon tank at 100 psig.

2.2.3.3 Gaseous Hydrogen

Gaseous Hydrogen is provided to the facility through a 3-inch facility line at 4,200 psig.

2.2.3.4 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 3-inch facility line at 4,200 psig.

2.2.3.5 Gaseous Helium

Gaseous Helium is provided to the facility through a 3-inch facility line at 4,200 psig.

2.2.3.6 Missile-grade Air

Gaseous Helium is provided to the facility through a 1.5-inch facility line at 3,500 psig.

2.2.3.7 Industrial Water

Industrial water is available at a pressure of 150 psig.

12.2.3.8 Hydraulic System

The hydraulic system has a flow rate of 10 gpm at 3,000 psig.

2.2.3.9 Instrumentation

The facility can provide 500 low-speed digital data acquisition channels at 100 SPS. 15 (expandable to 180) high-speed digital channels are available at 250,000 SPS. Also available are high speed and infrared cameras and control systems with video monitoring.

2.2.4 Solid Propulsion Test Facility



Solid Propulsion Test Facility

The Solid Propulsion Test Facility (SPTF), built in 1989, is a two-position stand designed for firing solid motors vertically upward or horizontally. The facility is used to provide performance data and evaluate the Space Shuttle's 48-inch solid rocket motor internal case instrumentation, non-asbestos insulation materials, nozzle designs, materials, and new inspection techniques. Tests of 24-inch single and double segment Solid Rocket Test Motors (SRTM) are also performed in the horizontal position.

The vertical test position is capable of withstanding 500,000 lbf thrust and 40,000 pounds of sideload, with the test article nozzle upward. The dimensions of the vertical structure are 12 feet wide x 12 feet long x 24 feet high. The horizontal position is capable of supporting 172,000 lbf of thrust and has been adapted to accommodate extra long, two segment 24-inch motors.

There are work platforms on the vertical position at 12 feet and 23 feet above ground level. Test hardware and other equipment are handled using a mobile crane. A portable weather shelter is placed over the horizontal position between tests. A weather station measuring wind direction, velocity, humidity, temperature and atmospheric pressure is also located at SPTF.

SPTA Data cables terminate in Static Input Units (SIUs) in Building 4553, where the signals are conditioned, digitized and multiplexed before being sent to the Data Acquisition Center in Building 4583.

The test motors are fired remotely from a control room in Building 4570 by igniting a bag igniter. A GN₂ quench system is also activated from this control room. The Solid Propulsion Test Facility is located in NASA Marshall's East Test Area.

2.2.4.1 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 1-inch facility line at 4,200 psig.

2.2.4.2 Missile-grade Air

Missile-grade air is provided to the facility through a 1-inch facility line at 3,500 psig.

2.2.4.3 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.2.4.4 Instrumentation

The facility can provide 250 low-speed digital data acquisition channels at 100 SPS. It can also provide 15 (expandable to 180) high speed digital data acquisition channels at 250,000 SPS. It is also equipped with high speed and infrared cameras and control systems with video monitoring.

2.2.5 Advanced Engine Test Facility



Advanced Engine Test Facility

The Advanced Engine Test Facility, also known as Building 4670, is a two-position, tri-propellant stand capable of evaluating and characterizing full-up engine and vehicle stage systems in a vertical configuration. The facility - used to assess and validate new propulsion technologies and prototype hardware for large rocket engines - is one of only a few test stands in the world that can accommodate large, liquid-fuel rocket engines.

The Advanced Engine Test Facility is a vertical stand, 406 feet in elevation (including the derrick boom). The super-structure is 267 feet tall and 162 ft² at the base. The foundation of the stand is keyed into the bedrock approximately 45 feet below grade. Capability is provided for static firing of 7.5 M-lb thrust stages. With modifications, the stand could accommodate stages up to 170 feet long and 40 feet in diameter, with thrust up to 12 M-lb. All control and instrumentation requirements are provided by the West Area Blockhouse, Bldg. 4674.

Originally designed for the SI-C engine stage cluster, the stand was modified in 1978-79 to perform structural tests for the Space Shuttle External Tank. In 1988, modifications were completed to allow single-engine testing with advanced components on the Space Shuttle Main Engine (SSME). Provisions were made in the redesign effort for future gimbaling requirements and a second test position. In 1998, the stand was further modified to accommodate ATLAS RD-180 engine testing. Stage handling is accomplished by using a 200-ton capacity overhead derrick and a 150-ton capacity lower derrick.

Water flow required to cool the deflector during static firing is 300,000 gallons per minute. The water is furnished from the East Area and West Area pumping stations at a flowrate of approximately 40,000 gallons per minute and 260,000 gallons per minute respectively. LOX, RP-1, and high pressure gas, nitrogen and helium, storage facilities are near the test stand. The engine exhaust gases are directed away from the blockhouse, permitting good visibility during static firing.

The test stand now has two positions. Position #1 can provide LOX and LH₂ to a test article and is rated for 375,000 lbf thrust. Thrust measurement is available. Position #2 can provide LOX/RP-1 to a test article and is rated for 900,000 lbf thrust. Thrust measurement is available in vertical direction. The Advanced Engine Test Facility is located in NASA Marshall's West Test Area.

2.2.5.1 Liquid Oxygen

Position #1 has a storage capacity of 23,000 gallons at a pressure of 150 psig. Position #2 has a storage capacity of 12,000 gallons at 130 psig. The facility has additional storage of 78,000 gallons at 100 psig.

2.2.5.2 Liquid Hydrogen

Position #1 has a storage capacity of 75,000 gallons at 50 psig. The facility has additional storage of 450,000 gallons at 100 psig.

2.2.5.3 RP-1

RP-1 storage is available in a 6,000 gallon tank at 130 psig. The facility also has a storage capacity of 14,000 gallons at 150 psig. Storage is also available in a 20,000 gallon tank.

2.2.5.4 Gaseous Hydrogen

Gaseous Hydrogen can be stored in a 11,400 ft³ vessel at 3,100 psig.

2.2.5.5 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 6-inch facility line at 4,200 psig and can also be stored in a 3,750 ft³ vessel at 4,200 psig.

2.2.5.6 Gaseous Helium

Gaseous Helium can be stored in a 2,500 ft³ vessel at 4,200 psig or a 90 ft³ vessel at 10,000 psig.

2.2.5.7 Missile-grade Air

Missile-grade Air is provided to the facility through two 1.5-inch facility lines at 3,500 psig.

2.2.5.8 Industrial Water

7,000,000 gallons of industrial water can be stored for Firex and deflector cooling. Firex provides water at 110,000 gpm at 150 psig. Deflector cooling is provided at 200,000 gpm at 150 psig.

2.2.5.9 Hydraulic System

The hydraulic system has two lines with flow rates of 15 gpm at 5,000 psig.

2.2.5.10 Instrumentation

The facility can provide 750 low-speed digital data acquisition channels at 100 SPS. 64 (expandable to 180) high-speed digital data acquisition channels 250,000 SPS are also available.

2.2.6 Hydrogen Cold Flow Facility



Hydrogen Cold Flow Facility

The Hydrogen Cold Flow Facility is a low-pressure, low-flow-rate system that tests hydrogen engine and subsystem components. Liquid hydrogen can flow from one 225,000-gallon storage tank through the test article into a second tank at a rate of 1,800 gallons per minute. The rate can be increased to 5,000 gallons per minute as needed. The facility also can run tests using gaseous nitrogen, helium and missile grade air. It can accommodate test articles up to 20 feet by 20 feet by 15 feet (6 meters by 6 meters by 4.5 meters) in size under roof or even larger sizes on the adjoining apron.

The Hydrogen Cold Flow Facility, also known as Test Facility 4626, is located in NASA Marshall's West Test Area.

2.2.6.1 Liquid Hydrogen

Liquid Hydrogen storage capacity at this facility is 225,000 gallons at 45 psig. The facility is also provided Hydrogen through an 8-inch facility line at 45 psig.

2.2.6.2 Gaseous Hydrogen

Gaseous Hydrogen is provided to the facility through a 1-inch facility line at 3,100.

2.2.6.3 Gaseous Helium

Gaseous Helium is provided to the facility through a 1-inch facility line at 1,500 psig.

2.2.6.4 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 1-inch facility line at 1,500 psig.

2.2.6.5 Missile-grade Air

Missile-grade Air is provided to the facility through a 1 -inch facility lines at 500 psig.

2.2.6.6 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.2.6.7 Hydraulic System

The hydraulic system has a flow rate of 10 gpm at 3,000 psig.

2.2.6.8 Instrumentation

The facility can provide 250 low-speed digital data acquisition channels at 100 PS. It can also provide up to 180 high-speed digital channels at 250,000 SPS. High speed and infrared cameras and control systems with video monitoring are also available.

2.2.7 Test Cells



Test Cells

NASA Marshall's Test Cells are open but segregated, explosion-proof test positions located on the north and east sides of Building 4583, with basic pressurants and propellants for testing scale model combustion devices and small rocket engines. The Test Cells are cost-effective facilities for short-duration tests of components that involve small buildup and require only small amounts of propellant.

Test Cell 100 is 25 x 20 feet and approximately 55 feet high located on the north side of Building 4583. This cell was used in the past for hazardous testing of cryogenic centrifugal pumps and other rotating equipment. It is protected from the weather by means of tracked, moveable steel doors.

Test Cell 101 is 25 x 26 feet and 18 feet 6 inches high, north-facing, also of reinforced concrete construction. It is open on one end with viewing windows to the control room on the other. A retractable overhead steel door protects it from the weather. This Cell is suitable for research and development performance tests on hardware such as cryogenic thermal pumping systems, cryogenic pumps and valves, environmental altitude component tests and cryogenic materials evaluation.

Test Cells 102 and 103 are east-facing 12 feet wide, 15 feet deep and 12 feet high, open on one end with viewing windows to the control room on the other. Retractable overhead steel doors protect each Cell from the weather. These test positions are suitable for research and development performance tests on hardware such as scale model combustors, cryogenic valves, pneumatic equipment, hydraulic equipment, water flow studies and small, solid propulsion test articles.

Test Cells 104, 105, 106, 107 and 108 are all east-facing 16 feet wide, 15 feet deep and 12 feet high, open on one end with viewing windows to the control room on the other. Retractable overhead steel doors protect each Cell from the weather. These test positions are suitable for research and development performance tests on hardware such as scale model combustors, gas generator combustors, heat exchangers, exhaust ducting, cryogenic valves, pneumatic equipment, hydraulic equipment, water flow studies and small, solid propulsion test articles.

Test Cells 109 and 110 are irregularly shaped cells with viewing windows to the control room on one end and a retractable overhead steel door at the other. Test Cell 109 is approximately 300 square feet and Test Cell 110 is approximately 400 square feet. These Test Cells are used for modeling of non-combustion processes and flows such as characterization of injector designs using water and other fluids.

The Test Cells are located in Building 4583 in NASA Marshall's East Test Area.

2.2.7.1 Gaseous Oxygen

A 236 ft³ tube trailer provides storage at 2,400 psig.

2.2.7.2 Gaseous Helium

A 238 ft³ tube trailer provides storage at 4,500 psig.

2.2.7.3 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 1-inch facility line at 4,200 psig.

2.2.7.4 Missile-grade Air

Missile-grade Air is provided to the facility through a 1 -inch facility lines at 3,500 psig.

2.2.7.5 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.2.7.6 Instrumentation

The facility can provide 250 low-speed digital data acquisition channels at 100 SPS. It can also provide up to 180 high-speed digital channels at 250,000 SPS. High speed and infrared cameras and control systems with video monitoring are also available.

2.3 Cryostructural Testing

NASA Marshall has the expertise to perform cryostructural testing to verify a vehicle can accommodate the stresses of launch and flight. Cryostructural testing validates a vehicle's structural integrity at ambient and cryogenic temperatures and also verifies failure modes.

Marshall's Cryostructural Test Facility has been used to test the Space Shuttle External Tank and various composite tanks.
Cryostructural test facilities

2.3.1 Cryostructural Test Facility



Cryostructural Test Facility

NASA Marshall's Cryostructural Test Facility can be used to evaluate the structural integrity of tanks and other propulsion components under a variety of conditions using

compression, sheer and tension loads, gases and cryogenics. The facility includes a two-foot-thick concrete test pad measuring 30 feet by 30 feet.

The Cryostructural Test Facility, also known as Building 4699, is located in Marshall's West Test Area. Cryostructural testing can also be conducted at Marshall's Hybrid & Engine Components Test Facility and the Hydrogen Cold Flow Facility.

2.3.1.1 Liquid Hydrogen

Liquid Hydrogen storage at 225,000 gallons is available at a pressure of 45 psig. 28,000 gallons local storage at 50 psig is also available.

2.3.1.2 Gaseous Hydrogen

Gaseous Hydrogen is provided to the facility through a 3-inch facility line at 3,100 psig.

2.3.1.3 Gaseous Helium

Gaseous Helium is provided to the facility through a 1-inch facility line at 4,200 psig.

2.3.1.4 Gaseous Nitrogen

Gaseous Nitrogen is provided to the facility through a 3-inch facility line at 4,200 psig.

2.3.1.5 Missile-grade Air

Missile-grade Air is provided to the facility through a 1 -inch facility lines at 3,500 psig.

2.3.1.6 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.3.1.7 Hydraulic System

The hydraulic system has a flow rate of 10 gpm at 3,000 psig.

2.3.1.8 Instrumentation

The Control System includes video monitoring, high speed and infrared cameras. The facility can provide 250 low-speed digital data acquisition channels at 100 SPS. It can also provide up to 180 high-speed digital data acquisition channels at 250,000 SPS.

2.4 Thermal Vacuum Testing

Vacuum testing by NASA Marshall's Space Transportation Directorate simulates the high vacuum and varying thermal conditions encountered by spacecraft. The Thermal Vacuum Test Facility in the East Test Area has the capability to test a wide range of rocket engine systems and subsystems, such as heat exchangers, combustors and valves under a variety of combined environments, including vacuum, heat and cryogenic exposure.

2.4.1 Thermal Vacuum Test Facility



Thermal Vacuum Test Facility

NASA Marshall's Thermal Vacuum Test Facility, also known as Test Facility 300, is a multi-position facility designed to conduct hazardous tests using cryogenics and heat loads to simulate liftoff, pressure ascent, and deep space profiles. Such tests are useful for developing insulation for external fuel tanks, screening composite materials exposed to heat, and predicting the performance of various materials at high altitudes and in deep-space environments. The Thermal Vacuum Test Facility is located in Marshall's East Test Area.

There are three vacuum chamber positions available at this facility, each with details below. There is also an ambient room and a blast environment wave simulator.

12-foot Position:

- * 12-foot diameter by 14 feet long (3 meters by 4 meters) carbon steel chamber
- * Elevated temperatures (e.g., radiant lamp testing of insulation materials)
- * Vacuum level: 10^{-3} torr
- * 20 BTU/square feet/sec radiant heat loads

15-foot Position:

- * 15-foot diameter by 15 feet tall (4.5 meters by 4.5 meters) stainless steel chamber
- * Deep space temperatures
- * Liquid nitrogen cold wall available
- * Vacuum level: 10^{-3} torr (future capability 10^{-6} torr)

20-foot Position:

- * 20-foot diameter by 35 feet tall (6 meters by 10 meters) stainless steel chamber
- * Deep space temperatures
- * Equipped with liquid nitrogen cold wall
- * Vacuum level: 10⁻⁷ torr

2.4.1.1 Liquid Hydrogen

The facility has a Liquid hydrogen trailer with a 12,000 gallon storage capacity.

2.4.1.2 Liquid Nitrogen

Liquid Nitrogen can be stored at 50 psig in a 13,500 gallon tank.

2.4.1.3 Gaseous Hydrogen

Gaseous Hydrogen is provided to the facility through a 3-inch facility line at 4,200 psig.

2.4.1.4 Gaseous Helium

Gaseous Helium is provided to the facility through a 1.5-inch facility line at 4,200 psig.

2.4.1.5 Gaseous Nitrogen

Gaseous Helium is provided to the facility through a 3-inch facility line at 4,200 psig.

2.4.1.6 Missile-grade Air

Missile-grade Air is provided to the facility through a 1.5 -inch facility lines at 3,500 psig.

2.4.1.7 Industrial Water

Industrial water is available at a pressure of 150 psig.

2.4.1.8 Hydraulic System

The hydraulic system has a flow rate of 10 gpm at 3,000 psig.

2.4.1.9 Instrumentation

The facility can provide 500 low-speed digital data acquisition channels at 100 SPS. It can also provide up to 180 high-speed digital channels at 250,000 SPS. High speed and infrared cameras and control systems with video monitoring are also available.

2.5 Aerodynamic Research

NASA Marshall has the expertise to perform research and development in support of the aerodynamic and aerothermodynamic design of space launch vehicles. Research and testing help determine the external shape of a vehicle and the effects of the rocket propulsion system on the vehicle. For instance, heat transfer from high-speed airflow to a vehicle's skin and heating of a vehicle's aft end caused by hot rocket jets must be tested vigorously on the ground before the vehicle is launched.

Wind tunnels supplemented by computational analysis are extensively used in aerodynamic design. NASA Marshall's primary workhorse, the Aerodynamic Research Facility, is an intermittent blowdown tunnel used for concept validation.

2.5.1 Aerodynamic Research Facility



Aerodynamic Research Facility

NASA Marshall's Aerodynamic Research Facility is an intermittent trisonic blowdown tunnel operated from pressure storage to vacuum or atmospheric exhaust. The test section measures 14 inches by 14 inches in two of the interchangeable test sections. The transonic section has interchangeable fixed contour blocks and provides for Mach numbers of 0.20 through 1.96. The supersonic section has fixed contour plates positioned by hydraulic screw jacks and provides for Mach 2.75 through 5.00. The trisonic facility also has a special test section for a variety of test subjects, including nozzles. Flow Visualization is available with Schlieren, Shadowgraphs, Oil flows, and High-speed video. The Aerodynamic Research Facility is located in NASA Marshall's North Test Area.

2.5.1.1 Tunnel Specifications:

Normally invisible shock waves are shown through a flow visualization technique using Schlieren photography to visualize the airflow field inside the facility. Some other tunnel specifications are as follows:

- * Reynolds Number: 1 to 18 million per foot
- * Stagnation pressure: 22 psia to 80 psia
- * Dynamic pressure: 2 psia to 20 psia
- * Stagnation temperature: Ambient to 200 F; normally 100 F
- * Air storage: 6000 cubic feet at 515 psia and 100 F
- * Vacuum storage: 42,000 cubic feet at 0.1 psia
- * Run time: 60 to 90 seconds (transonic), 30 to 40 seconds (supersonic)
- * Recharge time: 10 to 15 minutes (transonic), 15 to 20 minutes (supersonic)
- * Run rate: 15 to 20 runs per eight-hour shift
- * Angle of attack: -10 degrees to +10 degrees with added range provided by offset stings up to 90 degrees

2.5.1.2 Instrumentation

The facility has a 200 channel pressure scanning system capability. Forces and moments are measured by an internal, six-component, strain-gage balance.

2.5.2 High Reynolds Flow Facility

NASA Marshall's High Reynolds Flow Facility is a Ludwig tube-type tunnel capable of producing a maximum Reynolds number simulation of 200 meters per foot. The facility has a 32-inch diameter test section and operates over a Mach number range from 0.20 to 3.50. The facility is currently inactive, but could be reactivated if money and time are invested. The High Reynolds Flow Facility is located in NASA Marshall's North Test Area.

2.5.2.1 Tunnel Specifications

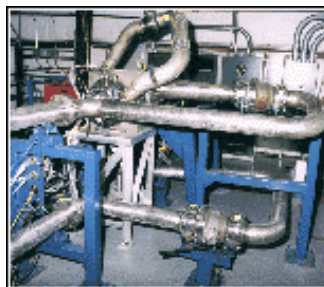
- * Reynolds Number: 7×10^6 to 200×10^6 per foot
- * Stagnation pressure: 45 psia to 686 psia
- * Stagnation temperature range: ambient
- * Run time: 350 milliseconds to 550 milliseconds
- * Run rate: 12 to 15 runs per eight-hour shift at stagnation pressures below 200 psia; five to seven per eight-hour shift at stagnation pressures above 200 psia
- * Angle of attack: +11 degrees to -18 degrees with added ranges with offset stings

2.6 Aero/Fluid Dynamics Testing

It is essential for engineers to understand how fluid dynamics and thermal environments affect spacecraft and aircraft. NASA Marshall has excellent test facilities for studying experimental fluid dynamic air and water flow testing.

In addition to facilities for studying flow dynamics, Marshall has the capability for complex path flow visualization. It gives engineers a realistic picture of what's going on inside complex machines and devices, such as injectors, manifolds and turbomachinery.

2.6.1 Water Flow Pump Test Facility



Water Flow Pump Test Facility

NASA Marshall's Water Flow Pump Test Facility is a closed-loop water flow facility used for testing full-scale models of liquid rocket engine pumps. It is located in Marshall's North Test Area.

2.6.1.1 Description

- * Closed-loop water system with 10,000-gallon reservoir
- * 350 horsepower motor
- * Dissolved oxygen monitoring
- * Flow meter and flow control quiet valve
- * Steam coil heating in reservoir
- * All stainless piping

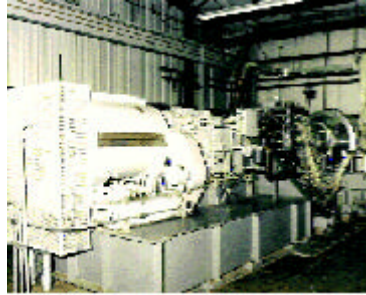
2.6.1.2 Performance

- * Flow rates up to 5,000 gpm
- * Inlet pressure: 5 psia to 165 psia
- * Discharge pressures up to 500 psia
- * Motor shaft speed: 360 rpm to 3,600 rpm shaft
- * Reservoir temperature: Ambient to 150 F

2.6.1.3 Instrumentation

Steady state data system is available for test article and facility pressure monitoring. Unsteady data is measured real-time and recorded with 1 Hz to 30 kHz bandwidths.

2.6.2 Air Flow Turbine Test Facility



Air Flow Turbine Test Facility

NASA Marshall's Air Flow Turbine Test Facility is an air blowdown system that discharges to the atmosphere through a turbine test article and backpressure control valve. The test facility provides experimental data and scientific studies of gas turbines. It is capable of controlling inlet total temperature, inlet total pressure, pressure ratio, delta pressure across the turbine rig, and turbine revolutions per minute. The Air Flow Turbine Test Facility is located in Marshall's North Test Area.

2.6.2.1 Description

- * Airflow blowdown system from 420 psia supply to atmospheric exhaust
- * Stainless steel tunnel with two 6,000 cubic feet carbon steel storage tanks
- * Closed-loop control of inlet pressure and temperature, pressure ratio and shaft speed
- * Flow conditioning system consisting of wide-angle diffuser, honeycomb flow straightener, screens and sine law contraction
- * 600 horsepower DC dynamometer with gearbox for power absorption and motoring
- * Ambient or elevated air temperature control provided by in-line stainless steel tube bundles heated by an offline electric heater system

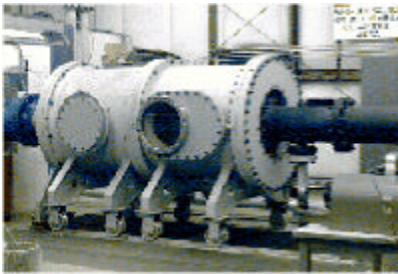
2.6.2.2 Performance

- * Shaft speed range: +/-14,000 rpm
- * Inlet pressure range: 30 psia to 300 psia
- * Inlet temperature range: 530 R to 830 R
- * Torque range: +/-1,000 foot-pounds
- * Power absorption/motoring capacity: 600 horsepower (900 horsepower transient)
- * Inlet flow turbulence intensity: approximately 10 percent
- * Test duration: 100 seconds to 20 minutes

2.6.2.3 Instrumentation

- * Subsonic mass flow venturi meters (2.1-inch and 3.4-inch diameter throats)
- * Inline torque meter with 30,500 and 1,000 feet-pound torque cartridges
- * 512-channel PSI electronic pressure scanning system
- * 240-channel low-level voltage input data system
- * 6 channel remote control instrumentation positioning system
- * 100 contact slip ring system for on-rotor measurements
- * Specialized instrumentation, including high-speed video/photo, as required

2.6.3 Nozzle Test Facility



Nozzle Test Facility

NASA Marshall's Nozzle Test Facility is an air/nitrogen blow-down facility used to evaluate the performance of rocket engine nozzles. It features variable test chamber pressure using a two-stage ejector system and nozzle model exit diameters up to 10 inches. The Nozzle Test Facility is located in NASA Marshall's North Test Area.

2.6.3.1 Performance

- * Nozzle core flow: 8 pounds per second at 25 psia to 350 psia, up to 350 F
- * Test chamber pressure range: atmospheric to 0.05 psia
- * Run time: 2 minutes to 3 minutes

2.6.3.2 Instrumentation

- * Steady and unsteady pressure measurement
- * Test cabin pressure and temperature
- * Up to 50 model pressures
- * Capable of calibrating load cells to measure thrust and side forces
- * Calibrated venturi for nozzle mass flow
- * Nozzle exit flows visualized with schlieren instrument
- * Industry quality data acquisition system with Internet connection

2.6.4 Solid Rocket Motor Air Flow Facility



Solid Rocket Motor Air Flow Facility

NASA Marshall's Solid Rocket Motor Air Flow Facility is a high-pressure blow-down system operating from a 1,900 pounds psig storage vessel and discharging to atmosphere through a solid rocket motor test article. The facility provides the full-scale Mach number and Reynolds number internal flow conditions for a 10 percent scale advanced solid rocket motor model. The facility can provide bore flow or mass injection through porous walls to investigate the effects on internal flow fields due to gimbaling a submerged nozzle, slot/port interactions, and other flow disturbances. The facility can also be configured for water flow testing. The Solid Rocket Motor Air Flow Facility is located in Marshall's North Test Area.

2.6.4.1 Description

- * Airflow blow-down system from 1,890 psia supply to atmospheric exhaust
- * Carbon steel tunnel with a supply tank farm of 9,100 cubic feet carbon steel storage tanks
- * Model inlets up to 16 inches in diameter

2.6.4.2 Performance

- * Inlet pressure range: 600 psia to 1,200 psia
- * Mass flow range: 20 pounds per second to 320 pounds per second
- * Test duration: 30 seconds to 300 seconds

2.6.4.3 Instrumentation

- * Sub-critical mass flow venturi meter
- * 150 channel PSI electronic pressure scanning system
- * 240-channel low-level voltage input data system
- * Specialized instrumentation, such as pressure probes/rakes, as required

2.6.5 Water Flow Inducer Test Facility



Water Flow Inducer Test Facility

NASA Marshall's Water Flow Inducer Test Facility is a closed-loop water flow facility used to test low head-rise liquid rocket engine pump components such as inducers. The loop can handle flow rates up to 2,000 gpm with discharge pressures up to 200 psia. A vacuum pump deaerates the water and allows running with inlet pressures as low as 4 psia. The Water Flow Inducer Test Facility is located in Marshall's North Test Area.

2.6.5.1 Description

- * 6-inch and 8-inch diameter pipe construction
- * Closed-loop, continuous water flow system (~400 gallon total volume)
- * 150 horsepower AC motor with 4:1 belt/pulley driveline
- * Variable speed controller for continuous adjustment of speed
- * Stainless steel 100-gallon inline accumulator/deaeration tank
- * 50 horsepower stainless steel auxiliary centrifugal pump
- * Air pressurization/vacuum system for loop pressure control
- * Water temperature control by way of steam

2.6.5.2 Performance

- * Shaft speed range: 1,000 rpm to 7,000 rpm (either direction)
- * Flow rate range: 250 gpm to 3000 gpm
- * Water temperature range: 60 F to 150 F
- * Inlet pressure range: 1 psia to 100 psia
- * Discharge pressure range: Atmospheric to 200 psia
- * Power/Torque Range: 100 horsepower/100 foot-pounds maximum
- * Deaeration: down to 3 ppm

2.6.5.3 Instrumentation

- * PC-based data acquisition system
- * 6-inch turbine type flow meter
- * Pressures (low frequency)
- * 50 channels in 1 psia to 65 psia range
- * 20 channels in 1 psia to 250 psia range
- * 28 analog tape high frequency channels

- * 100 contact high-speed slip ring system with shaft encoder
- * Specialized instrumentation, including high-speed video/photo as required

2.6.6 Low Density Flow Chambers

NASA Marshall has two low-density flow chambers designed for aerospace experiments needing low background pressure, while maintaining a high volumetric pumping speed. Typical experiments in the chambers include high-altitude gas dynamics, out-gassing, jet plume, micro-thruster and materials investigations. The 3-Foot Low Density Flow Chamber and 12-Foot Low Density Flow Chamber are located in NASA Marshall's North Test Area.

2.6.6.1 12-Foot Low Density Flow Chamber Description

- * 12 feet in diameter, 16 feet long
- * Six 32-inch oil diffusion pumps
- * CFM blower capacity
- * CFM vacuum pump capacity
- * One 12-foot diameter flanged head for access
- * Additional access through 12-inch blind flanges at various locations

2.6.6.2 12-Foot Low Density Flow Chamber Performance

- * Pump down to $10E^{-7}$ torr
- * Complete cycle in one hour
- * Automatic pump down to $10E^{-7}$ torr range with manual override capability

2.6.6.3 12-Foot Low Density Flow Chamber Instrumentation

- * Pressure measurements in control room with MKS controller and ION gauges
- * High speed and infrared cameras and control systems with video monitoring

2.6.6.4 3-Foot Low Density Flow Chamber Description:

- * Horizontal cylindrical tank 3.5 feet in diameter and 14 feet in length
- * Constructed entirely of stainless steel with vacuum exposed surfaces highly polished
- * Full-size hinged door at each end to permit easy access to the chamber and test fixtures
- * 12 8-inch ports located around the chamber for viewing
 - Pump system
 - 30 cubic feet per minute mechanical
 - 230 cubic feet per minute blower
 - Two 6-inch oil diffusion pumps
 - Two 10-inch diffusion pumps
 - Liquid nitrogen tubes in storage

2.6.6.5 3-Foot Low Density Flow Chamber Performance

- * 10^{-4} torr in 30 minutes
- * 10^{-6} torr in 90 minutes
- * 5×10^{-7} torr in 215 minutes

2.6.6.6 3-Foot Low Density Flow Chamber Instrumentation

- * Pressure measurements with MKS controller and ION gauges
- * High speed and infrared cameras and control systems with video monitoring

2.7 Injector Test Facility

NASA Marshall's Injector Test Facility is a pressure-flow facility used to evaluate the performance of injectors. The facility features two flow systems to deliver simulated, non-reactive propellants. The Injector Test Rig is located in Marshall's North Test Area.

2.7.1 Description

- * Flow delivery via pressurized supply vessels and throttled by flow control valves
- * Offline deaeration capability
- * Injectant filtration to 20 microns
- * Determination of spray mass distribution and mixture ratio possible using patternator to capture and measure injector discharge

2.7.2 Performance

- * Injectant pressures to 275 psig
- * Flow rates to 15 gpm on each delivery system

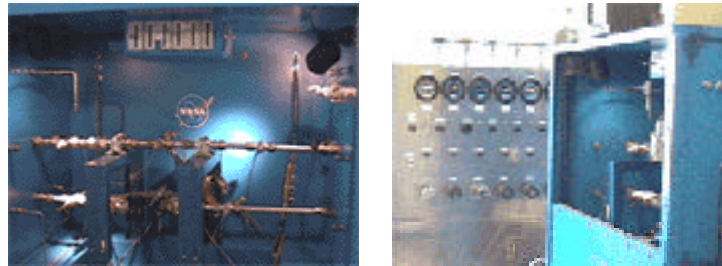
2.7.3 Instrumentation

- * Flow system and model pressure
- * Flow rate
- * Propellant simulant temperature
- * Spray mass distribution across 4-inch by 4-inch collection grid into 625 discrete collection tubes

2.8 Component Development & Control Mechanisms

NASA Marshall's Component Development Area is a new facility designed to test very small components in a flexible, cost-effective mode. The Control Mechanisms Laboratory has world-class capability in the design, development and evaluation of thrust vector control mechanisms used in launch vehicles and spacecraft.

2.8.1 Component Development Area



Component Development Area

The Component Development Area (CDA) at NASA Marshall supports technology development of rocket engine components, including valves, seals, bearings, ducts and lines.

The new facility is designed to test small components - 2 inches or less - in a flexible, cost-effective mode. The indoor facility is available to vendors as needed. It consists of an environmental chamber and necessary support equipment, pressure and leak testing hardware, and data acquisition and control hardware.

2.8.1.1 Component Development Area Features

- * Environmental chamber from +450 F to -320 F
- * Flow testing to 100 gpm (liquid) and 10,000 SCFM (gas) at reduced pressures. Gases include nitrogen, helium and air
- * Liquids include hydraulic, water and nitrogen
 - Pressures
 - 5000 psig for gases
 - 3000 psig hydraulic fluid
 - 5000 psig for water and liquid nitrogen
- * Hydrostatic up to 10,000 psig
- * Instrumentation for pressure, flow, position, temperature, leakage, speed and volume

Test parameters can be changed rapidly. While a variety of components can be tested in the facility, the device that's getting the most attention early on is the engine valve.

A new approach to rocket engine valves

Valves for next-generation launch vehicles must be lighter, cheaper and more reliable than today's components, so engineers at NASA Marshall are developing technology that could lead to new kinds of valves. While valves have been used successfully on rocket engines for over 40 years, the life cycle of valves is not clearly understood.

Knowledge gained through NASA Marshall's in-house valve design, development and testing will lead to simpler designs and better components. Lessons learned will help NASA write better specifications and verification plans for valves that will be built by vendors.

Simple testing of small valves can be more cost effective than analytical modeling, and can help manage risk by understanding the consequence and probability of failure.

The Component Development Area uses an environmental chamber with liquid nitrogen to test valves. Without liquid nitrogen, temperatures range from +450°F to -10 F. Liquid nitrogen is needed to cool the chamber from -10°F to -100°F. A liquid nitrogen bath in the Test Cell is also used for temperatures from -101°F to -320°F.

The data and control system accommodates 68 channels of data at sample rates to 5Ms/s. These channels can be configured in a variety of combinations. The system provides real-time process control, with 32 solid-state relays triggered from the Labview software program and six channels of analog output for control. Digital color video can be synchronized with the data, and near real-time data acquisition is available via the Internet.

Advanced Valve Technology Development

The Component Development Area will help the aerospace engineering community advance valve technology development. Using current processes and manufacturing technologies, Marshall's Mechanical Design team is designing and developing propellant system control valves that will reduce complexity and increase reliability. The simplified design will render valves that are easier to assemble, install and test when integrated with the engine.

The facility is also used to evaluate the application of emerging technologies for valve designs, with an overall objective of improving the state of the art in valve manufacturing and materials.

2.8.2 Control Mechanisms Laboratory



Control Mechanisms Laboratory

NASA Marshall's Control Mechanisms Laboratory is a world-class facility for control mechanisms development testing for applications requiring precision control mechanisms and systems. The lab has unique capability in the design, development and evaluation of thrust vector control mechanisms used in launch vehicles and spacecraft.

Lab engineers and technicians have experience in the design, test and program implementation for providing specialized components, such as:

- * Electromechanical actuators
- * Hydraulic actuators
- * Accumulators
- * Pumps
- * Auxiliary propulsion devices
- * Servo actuation mechanisms

Using special test fixtures and equipment and data acquisition systems, trained personnel develop components and subsystems from concept through flight qualification.

Inertia load simulators, static load test fixtures, and component level test items allow testing of thrust vector control actuators ranging from less than 1000 pounds output force up to the largest thrust vector control actuators used in the mammoth Saturn V, the United States' most powerful launch vehicle.

The versatile laboratory was developed primarily for testing electrohydraulic mechanisms, but also supports testing of electromechanical and pneumatic devices. A battery pack power source provides DC power up to 300 VDC at 300 amps.

Various static load test fixtures apply known loads to determine output piston velocity versus load. Measured and controlled tension and compression loads are also used for structural verification of hardware and calibration of flight instrumentation that measures force.

Static load test fixture features:

- * Hydraulically loaded with variable pressure systems operating double-acting cylinders
- * Largest test fixture capable of load forces approaching 100,000 pounds
- * Smaller test fixtures capable of 5,000 pounds to 30,000 pounds of force
- * Accommodates actuator strokes from 0.5 inch to +/-6.4 inches
- * Hydraulic flow capability of 400 gpm at 5000 psi for both load bench and actuator operation

Simulators

The Control Mechanisms Laboratory has five dynamic load, or inertia, simulators that are used for testing frequency response and stability analysis. Inertial loads can be varied to simulate a variety of rocket engines. The actuator mounting structure and attach point geometry can be varied to change the effective structural compliance to adapt to most liquid and solid fuel propulsion thrust vector control system requirements.

The two largest simulators are currently configured to simulate the structural compliance, inertia and mounting provisions of the Space Shuttle's Solid Rocket Booster aft skirt and are used for dynamic verification of the booster's thrust vector control servo actuator. The Solid Rocket Booster is rated at 2.7 M-lb thrust.

One of the large simulators can be configured for Space Shuttle Main Engine actuator testing. A smaller dynamic load simulator accepts actuators with 4 inches to 48 inches between centers and output forces ranging from 500 pounds to 18,000 pounds. Two additional simulators provide spring forces that simulate control surfaces. These provide loads up to 12,000 pounds.

Other dedicated test fixtures in the Control Mechanisms Laboratory allow characterization of various control mechanisms, such as:

- * Rotary output propellant control valve actuators
- * Positioning and pointing mechanisms
- * Berthing and docking mechanisms
- * Control mechanisms and subsystems

The lab is fully supported by state-of-the-art test equipment, such as signal analyzers, digital and analog measuring devices, and data acquisition and evaluation systems. The lab has a fiber optic link to the Marshall Avionics Systems Testbed (MAST), a Marshall Center Avionics Department facility, for hardware-in-the-loop simulation. Limited shop capability for light fabrication and test fixture preparation is available. The facility also has a clean room with a class 100K rating and laminar flow benches that provide a 10K rated workspace.

2.9 Hot Gas Facility



Hot Gas Facility

Activated in 1976, the Hot Gas Facility (HGF) was redesigned and reactivated in 1987. The HGF is a nominal Mach 4.1 Aero-Thermal Tunnel that burns a lean mixture of gaseous hydrogen and missile grade air. Test conditions closely simulate flight environments for heating rates, local pressure, recovery temperature, and run duration. HGF has been used for testing Solid Rocket Booster (SRB) and External Tank (ET) thermal protection system materials and configurations.

The HGF is a gaseous hydrogen/air combustion-driven wind tunnel used primarily for thermal protection system testing and aerothermal environments definition. It can simulate aerodynamic heating environments such as Space Shuttle ascent trajectories. During a test combustion products are expanded from the combustion chamber through a two dimensional nozzle into a 16 in x 16 in x 40 in long test section. A Mach 4 flow environment is induced and from 3.5 to 25 $\text{btu/ft}^2/\text{sec}$ of convective heating can be obtained.

The tunnel has been upgraded to include a 300kW radiant heat system, a model insertion system with varying wedge angles, and test section shutter doors to protect the test article from start up and shut down shocks. The IHGF radiant heat system provides from 0 to 35 $\text{btu/ft}^2/\text{sec}$ radiant and can be combined with the Mach 4

convective heat inputs for a world unique test facility ideally suited for base heating environments. Radiant-only heating with programmable vacuum is also available.

All heating environments can be individually profiled within the parameters of the facility to follow a prescribed flight heating profile. If requested, oxygen may be added to the combustor flow to maintain 21% oxygen. The HGF also offers thermal imaging support in order to provide our customers with real time thermal response and gradients of the test article. Test environments can also be generated to follow a test article temperature profile. The HGF can provide evaluation of thermal performance, including recession rates, heat transfer rates, temperature profiles, and structural integrity.

Video of test articles can be recorded from 30 to 500 frames per second and high speed 16 mm movie film can record up to 10,000 frames per second. Up to 72 channels of instrumentation can be dedicated to each test article, with more channels available upon request.

2.9.1 Hot Gas Test Parameters

- * Mach 4 Flow
- * GH_2 /Air Combustion-Driven
- * Convective, Conductive and Radiant Heating
- * 0 - 25 degree angle of insertion for test articles
- * 0-300 seconds run duration
- * 300kW Radiant Heat
- * 1500-3000 degrees F Total Temperatures
- * Infrared Thermal Imaging
- * Video Imaging during testing

2.10 Optical Propagation Tunnel Facility

The Optical Propagation Tunnel Facility is a modified access tunnel between Buildings 4570 and 4572. This facility is used for testing in-space automated optical rendezvous systems, sensors and components.



Optical Propagation Tunnel Facility

2.10.1 Description

- * 330m long, 8' wide, 8' high
- * Straight line-of-sight
- * Fresh air supplied or
- * Zero air movement
- * Controlled access in restricted area
- * Overhead trolley capability
- * No stray light
- * Reduced EMF flux
- * Full communications capability
- * Optical fiber data links available

2.11 Dynamic Test Stand



Dynamic Test Stand

The Dynamic Test Stand is located in the East Test Area. The structure is the highest in Alabama. The tower is 360 feet high with a 64-foot stiffleg overhead derrick making the total height 425 feet. Each side of the square base is 98 feet long. The crane on top has the following capabilities: main hook, 200 tons at 70-foot radius, auxiliary hook, 40 tons at 100-foot radius. The secondary derrick: main hook, 175 tons at 50-foot radius.

This stand was used to test the entire Saturn V vehicle and separate flight configurations. Vibration loads can be induced in the pitch, yaw, roll, and longitudinal axes to obtain resonant frequencies and bending modes. It was also used to perform dynamic testing on Space Shuttle.

The Low Gravity Test Facility is located in a bay of the Dynamic Test Stand. This facility is utilized in low gravity fluid mechanics and thermodynamics phenomena studies, calibration of accelerometers, and subjecting flight instrumentation to low gravity studies. This facility provides 296 feet of free fall height with a maximum drop

weight of 4,000 pounds and a 25g deceleration of the drag shield. The drag shield is capable of taking a test package envelope size of three feet diameter by four foot high, with a weight of 400 lb. The package is capable of a deceleration range of 15-25 g's. The test environment of 2.5×10^{-2} g maximum and 10^{-5} g minimum can be achieved.

Building 4550 provides experimental data to verify and correlate analytical finite element models of flight hardware and dynamic loads environments for vibration, vibroacoustics, and pyrotechnic shock testing.

2.12 F-1 Static Test Stand



F-1 Engine Test Stand

The F-1 Engine Test Stand is a vertical engine firing test stand, 239 feet in elevation and 4,600 ft² in area at the base. The foundation of the stand is keyed into the bedrock approximately 40 feet below grade. Capability is provided for static firing of 1.5 M-lb thrust RP-1/LOX engines. With modifications, the stand could accommodate engines with thrust levels up to 3.0 M-lb. All control and instrumentation requirements are provided by the West Area Blockhouse. The stand has a deflector that is water cooled. Water flow rate is 135,000 gpm at 125 psig. There is also a 100-ton overhead derrick.

2.12.1 Propellants

2.12.1.1 Liquid Hydrogen

The test stand has a 191,500 gallon LH₂ storage tank.

2.12.1.2 Liquid Oxygen

The test stand has a 141,000 gallon LOX storage tank. There is a 105,000 gallon LOX run tank at 150 psig. There is also a 30,000 gallon high pressure run tank at 1,500 psig planned for future construction.

2.12.1.3 RP-1

The test stand has a 312,000 gallon RP-1 storage tank. It also has a 50,700 gallon RP-1 run tank at 100 psig. There is also a 18,000 gallon RP-1 high pressure run tank at 1,500 psig planned for future construction.

2.12.2 Utilities

- * GN₂ is provided to the facility through a 3-in. line at 5,000 psig.
- * GHe is provided to the facility through a 1.5-in. line at 5,000 psig.
- * Air is provided to the facility through a 1.5-in. line at 3,500 psig.
- * There are two 3.5 M gallon vessels that provide storage of industrial water.

2.13 West Test Area Industrial Water Supply System



West Test Area Industrial Water Supply System

Industrial water in the West Test Area is stored in two 3,000,000 gallon cylindrical reservoirs. The reservoirs are 125 feet in diameter, 40 ft high, and are connected by three 36-inch equalizing lines. A 12-inch fill line from the Redstone Arsenal Industrial Water System and an automatic valve system keep the reservoirs full and ready for use. The reservoirs are provided with an overflow system.

Thirteen 36-inch lines from the reservoirs supply water to the suctions of thirteen 20,000 diesel driven pumps which deliver up to 270,000 gpm at 185 psig pressure. When tied in with the East Test Area pumping system, a total of approximately 320,000 gpm can be supplied for deflector cooling and Firex systems on the test stands.

The main discharge water line from the pumping station is 96 inches in diameter, contains a flow meter, and runs to the Advanced Engine Test Facility deflector where it

manifolds to the 54-inch line from the East Area. A 30-inch line loops south off the main 96-inch line and connects with the 30-inch East Area loop line.

A 72-inch line runs north off the main 96-inch line and continues to the F-1 Engine Test Stand. It is intersected by the 54-inch line from the East Area, thereby completing a ring line between east and west areas.

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APPENDIX A

ACRONYMS AND ABBREVIATIONS

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ACRONYMS

—A—

ASRM	Advanced Solid Rocket Motor
ASTP	Advanced Space Transportation Program

—B—C—

CDA	Component Development Area
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—D—

DC	Direct Current
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—E—

EMF	Electromagnetic Force
ET	External Tank

—F—G—

GH ₂	Gaseous Hydrogen
GHe	Gaseous Helium
GN ₂	Gaseous Nitrogen
GM	Gaseous Methane
GOX	Gaseous Oxygen
GPM	Gallons per Minute

—H—I—

HGF	Hot Gas Facility
H ₂ O	Water
H ₂ O ₂	Hydrogen Peroxide
HP	High-Pressure (3,000 psi to 8,000 psi)
HPA	High-Pressure Air

—J—K—L—

JP	Jet Propellant
JSC	Johnson Space Center
LH ₂	Liquid Hydrogen
LM	Liquid Methane
LN ₂	Liquid Nitrogen
LOX	Liquid Oxygen

—M—

MAST	Marshall Avionics Systems Testbed
MP	Medium Pressure (1,000 psi to 3,000 psi)
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center

—N—O—P—

NASA	National Aeronautics and Space Administration
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—Q—R—

RLV	Reusable Launch Vehicle
RP	Rocket Propellant

—S—

SCFM	Standard Cubic Foot per Minute
SIUs	Static Input Units
SPS	Samples Per Second
SPTF	Solid Propulsion Test Facility
SRB	Solid Rocket Booster
SRTM	Solid Rocket Test Motors
SSC	John C. Stennis Space Center
SSME	Space Shuttle Main Engine

ABBREVIATIONS

°F	degree Fahrenheit
CH ₄	methane
ft	feet
ft ²	square feet
ft ³	cubic feet
gpm	gallons per minute
H ₂	hydrogen
He	helium
Hz	hertz
in.	inch
kHz	kilohertz
kW	kilowatt
lb	pound
lbf	pounds force
M	million
M-lb	million pound
Ox	Oxygen
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch atmosphere
psig	pounds per square inch gauge
rpm	revolutions per minute
s, sec	second
torr	millimetre of mercury
VDC	volts direct current